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The Psychological Review

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The Psychological Review.

STUDIES FROM THE BRYN MAWR COLLEGE PSYCHOLOGICAL LABORATORY.

An Experiment in Learning to Make Hand Movements.[1]

BY PROFESSOR JAMES H. LEUBA AND MISS WINIFRED HYDE,

Bryn Mawr College.

Between the first and the thirtieth of March, 1904, forty-two students averaging twenty-one years of age, nearly all undergraduate, undertook to learn to read and write German script under the conditions mentioned below.

The task of these forty-two students was a double one: to put English prose into German script and to write in English script English prose which they had before them in German script. Thus, only German script, and not the German language, is involved in this experiment. They were asked to do as much work as possible and at the same time to try and write with constant distinctness.

The subjects were divided in two groups. The twenty-six subjects of Group A began with the writing. Of these, twelve, after having gained a considerable writing ability, applied themselves to the reading. The sixteen subjects of Group B began with the *reading* of the German script. Of these, thirteen passed later on to the task undertaken first by the other group, *i. e.*, the writing in German script.

[1] This investigation was planned by the undersigned and Miss Hyde, at the time a graduate student at Bryn Mawr College. The data were gathered by the latter who intended to make the experiment her own. But, after having plotted the individual curves, lack of time compelled her to leave the work unfinished. In the spring of 1905 the undersigned took it up where she had left off and wrote the present paper.—J. H. Leuba.

Every period of work was of twenty minutes' duration. Of Group A, six subjects met twice a day, after breakfast at 8:40 A. M. and after luncheon at 1:40 P. M.; seven met once a day at 1:40 P. M., except No. 7, who worked at 8:40 A. M.; six met every other day at the same afternoon hour, and the others every three days, also in the afternoon. Of Group B, five met twice daily at the hours first stated; five once a day at 1:40 P. M., three met every other day at the same hour and the others every third day, also at the same afternoon hour.

In a few cases students prevented from meeting at their accustomed time changed their hour.

A time-keeper called time at intervals of five minutes during the twenty-minute periods and the subjects made a mark in their records, thus enabling us to follow the work done during each five minutes. When, as it happened a number of times, the time-keeper forgot to call time, he then gave the signal after six minutes, and reduced the following period to four minutes. The inequalities thus introduced in the records was corrected by taking as a basis for calculation the number of letters written or read during the whole period. A few, very few, other irregularities were corrected in the same, or in a similar way. They could not have had any noticeable influence on the conclusions here set forth.

Eleven of our subjects (Nos. 1, 7, 12, 13, 14, 24, 26, 27, 31, 33, 39) had already had some practice in German script. But it was, in every case, several years before and amounted to extremely little, except in the case of No. 7, who still remembered a few letters. The records of these persons were, however, left out in the consideration of every point in which previous practice might have modified the results.

Contents :

1. General comments on the individual curves and analysis of the psycho-physiological processes with which this experiment is concerned.

2. The influence on writing of reading practice and vice-versa.

3. Fatigue.

4. *The fluctuations in effectiveness: a comparison of the amount of work done during the successive five minutes of the twenty-minute periods.*

I. *General Comments on the Individual Curves and Analysis of the Psycho-physiological Processes with which this Experiment is Concerned.*

In the eight annexed curves (Charts 1 and 2), given as samples of individual curves, each segment corresponds to one period of work. The figures to the left indicate the number of letters written or read. The height of each square is equivalent to twenty-five letters.

The irregularities observed by previous investigators who dealt with the acquisition of motor skill[1] are in evidence in our curves: instead of ascending steadily they frequently show drops without any periodicity.

The causes of these irregularities are no doubt many. The fact that instead of decreasing with habituation the irregularities continue approximately as marked and, in the case of the writing curves, become even greater, might point to weariness as an important factor. At first, and for a number of periods, novelty helps the student to keep to the highest point of efficiency. But, when the task has become monotonous, there are moments of relaxation. Slight fatigue, no more overcome by interest, brings about a flagging of attention. The reader should, however, observe that since each element of the curves represents an absolute and not a proportional gain, the irregularities of the curves would increase even though the irregularities of the relative gains should not: a loss of 5 per cent., for instance, would be expressed by a much smaller drop at the beginning of the curve when only 200 or 300 letters are written in twenty minutes than later on when a thousand letters are written in the same time.

The rise of the curves, very rapid at first, soon decreases considerably, but no plateau appears within the limits of our curves. What would have happened, if the practice had been continued

[1] See, for instance, Swift's 'Studies in the Psycho-physiology of Learning,' *Amer. Jr. of Psy.*, 1903, Vol. XIV., p. 211.

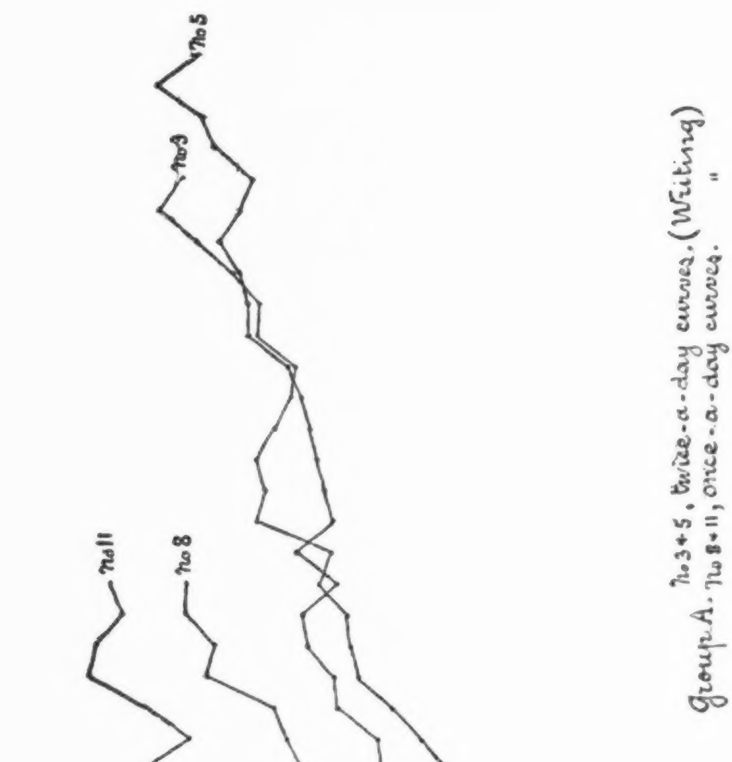


Chart I.
Group A. no 3+5, twice-a-day curves. (Writing)
Group A. no 8+11, once-a-day curves. "
no 5
no 3
no 11
no 8
2000
1800
1600
1400
1200
1000
800
600
400
200
100
0

CHART I.

much longer, can only be inferred. The twice-a-day curves stop at a maximal rate of from 1,400 to 1,800 German letters a period, whereas a test of the speed of these subjects in writing in English gave an average of 2,277. The subjects were therefore far from having reached the rate of writing possible to them in English. The flattening of the curves, already well marked

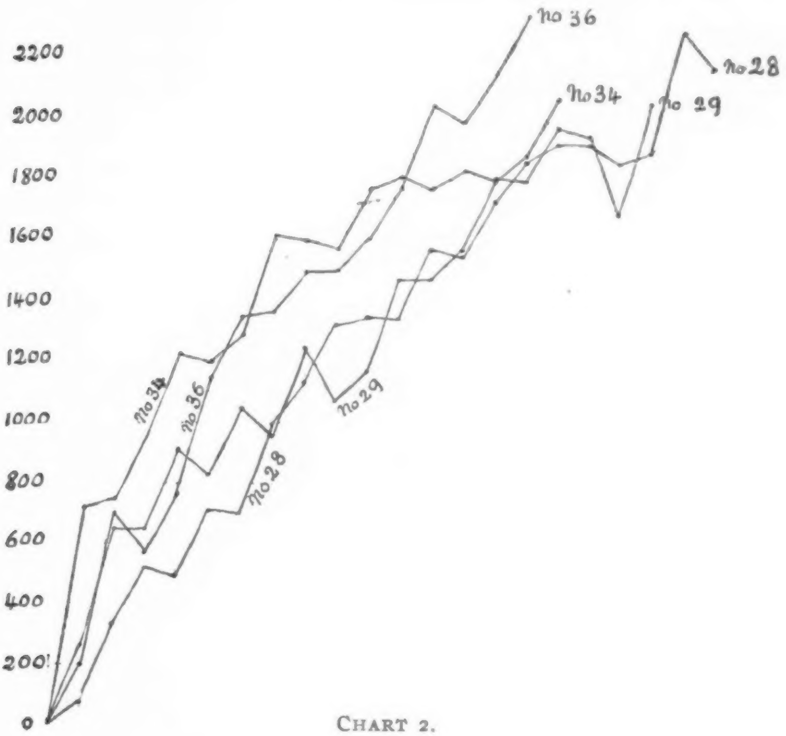


CHART 2.

Group B. no 28 & 29, twice-a-day curves. (Reading.)
no 34 + 36, once-a-day curves "

in the longer of the writing curves, would no doubt have increased with the continuation of the practice. Would a characteristic rise have appeared later on? There are no reasons known to us for an affirmative answer; for even though the several psycho-physiological processes involved in the learning of German script under the conditions of this experiment, should

appear in a definite order of succession, they do not each reach complete maturity before the next one becomes possible. On the contrary, several of them grow together, and before they have been fully perfected the next ones are already in operation.

But what are the several processes involved in learning to put in German script English prose ?[1]

Leaving out of consideration what belongs to the volitional order, and speaking as if perceptions and representations ordinarily led of themselves to purposive movements, we have first the establishment of associations between, on the one hand, the dynamic system formed by the visual perceptions of discreet English letters and the speech-motor and auditory representations they evoke, and, on the other, the visual perceptions of the corresponding German letters seen by the subject in the alphabet with which he is provided:

Visual perception of English letters plus speech-motor and auditory representations.	Associated with visual perceptions of German letters.

But, as the German letters are seen, they are also inwardly named and heard (in English), and in addition, the intent to write them determines motor discharges which reproduce more or less perfectly the letters. The preceding schema must therefore be completed thus:

Visual perception of English letters plus speech-motor and auditory respresentations.	Associated with visual perceptions of German letters, associated themselves with	Speech-motor and auditory representations of the letters plus the motor and other sensible antecedents of the motor discharge.

The repetition of this process under the pressure of the desire to write rapidly brings about a double short circuiting. (1) The student need no longer refer to the alphabet; the *perception* of the German letters becomes unnecessary. It is replaced by representation of them. (2) At the same time the

[1] Comp. 'The Acquisition of a Hierarchy of Habits,' by Wm. L. Bryan and Noble Harter, PSY. REV., Vol. VI., 1899.

speech-motor and the auditory representative elements which follow upon the sight of the German letters and precede the writing of them, drop out. This means the formation of a direct connection between the visual image of the German letters and the cue to the motor discharge. We come thus to the second phase of the first stage of the process:

Visual perception of English letters plus speech-motor and auditory representations.	=	Visual representation of German letters.	=	The motor and other sensible antecedents of the motor discharge.

With sufficient practice this second phase passes into a third one, in which the ordinary speech-motor and auditory associates of the perception of the English letters and, in addition, the sensible antecedents of the motor discharge fall out of consciousness. At this culminating point of the first stage the writing follows immediately — automatically — upon the representation of the German letters, itself preceded by nothing more than the perception of the English letters. The automatization may even go so far as to eliminate the image of the German letters; so that, finally, they may be written directly on the perception of the English letters without any conscious intermediary.

But when this automatic process has become possible, frequent lapses are observed which bring back the subject for a while to an earlier, less mechanical, phase.

So much for the first stage. So far the individual letters have been the objects of attention. The moment comes when groups of letters — syllables or words — are substituted for the letters. Instead, for instance, of starting successively from the perception of the three letters composing the article *the*, the *word* appears in the mind as a whole, as a unit. Its auditory and visual apprehension and the sensational outcome of the innervation which would utter it and write it, take the place of the three successive and completely different mental contents represented respectively by the three letters *t*, *h*, *e*.

The substitution of the word-apprehension for that of the component letters is, it hardly need be said, of the greatest practical importance. It is also one of the most interesting facts encountered in the psychology of writing and of reading.

How is this substitution made possible?

While it is true that the *writer* at first considers the letters separately, he does not fail to also apprehend the word which they form. (At the beginning this may be true of the small words only.) When he wishes to write, for instance, the word *man*, before he pays attention to the letters he apprehends the word and pronounces it mentally. Again, upon the completion of the last letter, the word as a whole reappears in consciousness. The schema given above is therefore incomplete; it should begin and end with the apprehension of the word itself. As the *writers* become familiar with the forms of the German letters and cease to be dependent upon the sight of them, the word-apprehension becomes an increasingly considerable part of the consciousness accompanying the writing and, when the final phase of the first stage has been reached, it is found that the word-consciousness has been, in the case of many small and oft-recurring words, substituted for the separate letters as cue to the writing.

The substitution of the word for the letters is thus seen to take place in the same way and according to the same principles as the earlier substitution of the image of the German letters for the perception of them.

The subjects forming Group B began, as already said, with the reading of English prose put in German script. They were, however, not only to read the German script, but to write it out in English. These *readers* passed from the visual perception of the German letters (devoid at first of any meaning) to the writing of the understood English letters. In every respect other than this different starting point and what evidently follows from it, the psychological processes are the same in the case of Group B as in that of Group A.

The fact which we have affirmed in saying that each particular element of the learning process was not perfected before some other, higher, ones appeared, is established by introspective evidence and confirmed, it seems, by the absence of plateaux in the curves. It was with our subjects as with Swift.[1] "All factors of

[1] 'The Acquisition of Skill in Typewriting,' Edgar James Swift, PSY. BULL., I., No. 9, Aug. 15, 1904, p. 302.

the perfected process have clearly been present almost from the start and the only justification for characterizing any particular stage by one element rather than the other is the prominence of the one or the other factor." Small words are quite early dealt with as units. This taken together with the unsteadiness of the recently formed syntheses would lead one to expect an ascending curve without genuine plateaux but with many irregularities.

II. *The Influence on Writing of Reading Practice and Vice Versa.*

The figures given in the following table are averages of the work done by all the subjects except those who had some acquaintance with German script at the beginning of the experiment.

GROUP A. (Writing preceded reading.)

First writing period	260 letters.
Second " "	414 "
Last " "	1,319 "
First reading period (after an average of 19 writing periods)	1,147 "

GROUP B. (Reading preceded writing.)

First reading period	346 letters.
Second " "	660 "
Last " "	2,070 "
First writing period (after an average of 15 reading periods)	470 "

It may appear surprising that after having acquired a degree of skill in reading German script measured by 2,070 letters (written in English script), the subjects should have been able at first to turn into German script only 470 English letters, *i. e., hardly more than was achieved, already in the second period, by those who had not had previous reading training.*

What the 'readers' had learned was to recognize *visually* the German letters and to express that recognition in the familiar movements tracing the English letters. The figures given above show plainly that visual recognition — a visual acquaintance sufficient for identification — is a very small part of what has to be acquired in order to be able to reproduce with the hand identified forms. Whoever has tried to reproduce from memory a map, every part of which could have been easily recognized, has felt the difference there is between rec-

ognizing a visual form and reproducing it. But a more thorough comparison of the reading and of the writing processes is needed here.

When reading, the subject, starting from the German script, endeavors to pass to the writing of the English forms already known to him. In doing this he passes through an intermediary step; the naming of the letters. When writing, he starts from the English script and tries to write the corresponding German forms. Here also he passes through the intermediary step of naming the letters. In both cases associations have to be established between the English and the German forms, but whereas in reading the movement of attention is from the second to the first, in writing it is from the first to the second.

Now, it has long been known that the ability to recall a series of ideas following each other in a particular sequence does not carry with it the ability to repeat it in another order. Ebbinghaus and others have, however, shown that something is gained by learning in one order a succession of speech movements which one wishes to reproduce in another. The difference between the number of German letters written in the first period by those who began with the writing (260) and the number of German letters written in the first period by those who had had the reading practice (470) measures this gain in the present instance.

If we consider now the advantage derived from a writing knowledge when learning to read (Group A), we find that whereas, on an average, 1,319 letters were written in German during the last writing period, only 1,147 German letters were read and written in English during the first succeeding reading period, a loss of 172 letters! Whence this surprising loss? Does not the learning to write involve all the elements which enter into the learning to read and, in addition, the acquisition of new hand movements? Yes, the elements are the same, but not the direction of the associations. In the one case, as we have just said, the visual perception of the German letters is associated with the English forms, in the other it is the reverse.

The considerable gains shown in the first reading period following the writing practice over the first reading period not

preceded by writing — a gain of 801 letters — is to be ascribed to three causes: (1) the familiarity gained, while writing, with the appearance of the German letters; (2) the associations established, although they link *A* with *B* and not *B* with *A*; (3) the undeniable, although slight, reading practice gained by the writers in the very process of writing. For, as one writes, and especially as one pens the last letter of a syllable and of a word, it is almost impossible not to read what has just been written.

III. *Fatigue.*

A. Comparison of the amount of work done in two daily practices, in one daily practice and in one practice every other day, each of twenty-minute duration.[1]

Chart 3 shows that the gains in writing-skill for equal amounts of time was least for those who worked twice a day and greatest for those who practiced once a day or every other day. Practice every third day gave gains half way between the extremes.[2]

Curve *A* is an average twice-a-day writing curve; *B* an average once-a-day curve; *C* an average every-other-day curve and *D* an average every-third-day curve. *A* and *B* are each made out of 5 individual curves, while *C* and *D* are made out of 4 and 3 individual curves respectively.

AVERAGE NUMBER OF LETTERS WRITTEN IN TWENTY MINUTES.

	Twice-a-Day. Subjects	Once-a-Day.	Every-Other-Day.	Every-Third-Day.
After 5 practices.	625	825	780	750
After 10 practices.	865	1,115	1,175	985
After 16 practices.	1,015	1,540	——	——

[1] Previous experimenters on the general question of the acquisition of motor skill either did not regard the question of rest-intervals or dealt with it so differently from us that their results are not comparable with ours. Amberg, Rivers and Kraepelin, and Lindley have studied the influence, upon adding and memorizing, of periods of rest varying from 5 minutes to an hour in duration. Swift has recorded in several places the effect on motor efficiency of a practice-interruption of several weeks and even of several months.

[2] In tracing these and also the other curves reproduced here the records of the subjects who had had previous practice were omitted.

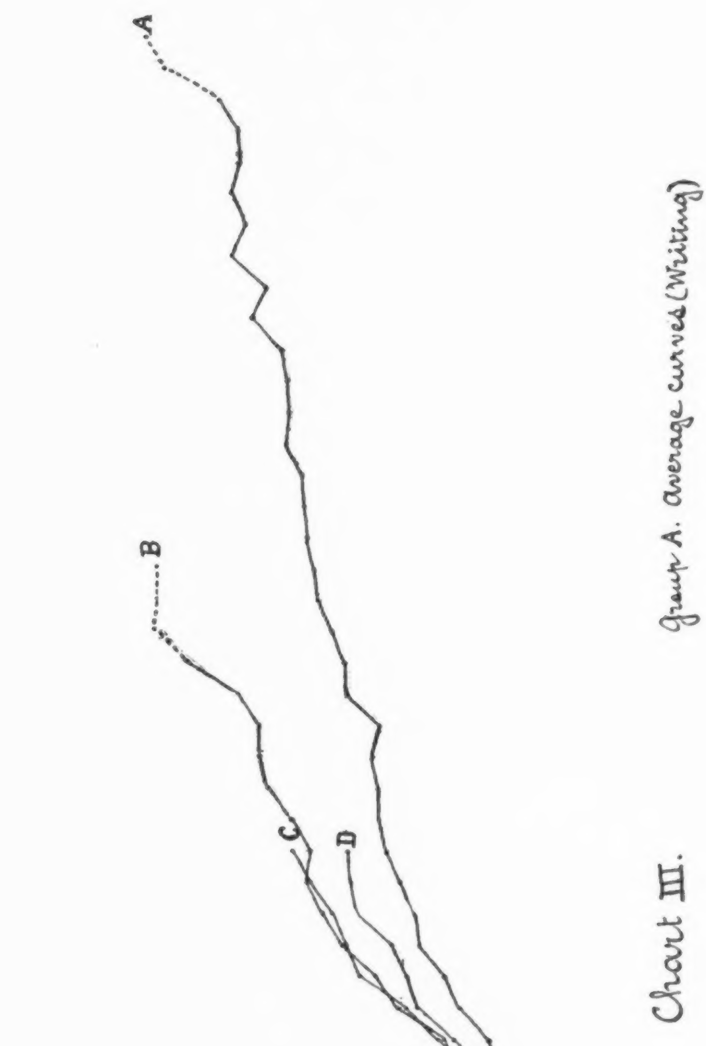


Chart III.
Group A. Average curves (Writing)
A
B
C
D
2000
1800
1600
1400
1200
1000
800
600
400
200
0

CHART 3.

The once-a-day and the every-other-day curves fall upon each other. It is a matter for regret that these two curves and the every-third-day curve could not have been continued as long as the twice-a-day curve. The figures on p. 361 will help in establishing the correspondence existing between these curves.

Two conclusions seem, therefore, warranted: (1) Under the conditions of this experiment the fatigue incurred in learning to write new script is too great to give the best results when there are two twenty-minute practices each day. (2) An interval of three days between the practices is too long to give the most economical results.

If the fatigue detrimental to the twice-a-day writers arose mainly from the efforts involved in learning to make *new* hand movements and not from the other factors, the reading curves should not show the differences we have just noticed in the writing curves. Unfortunately our data concerning reading are not full enough to admit of safe conclusions.

The average once-a-day and every-other-day reading curves of Group A are made up of too few individual curves and are too short to have any value. In Chart 4, *C* (the every-other-day and the every-third-day curve) is an average of only two curves and stops after 8 practices. It cannot, therefore, be of any service in this connection. The other curves of this chart do not differ enough one from the other to permit of discrimination. *A*, the twice-a-day curve, is an average made out of 5 individual curves, and *B* is a once-a-day curve made out of 4 individual curves. Curve *A* of Chart 5 would seem to indicate that two reading periods of 20 minutes are somewhat better than one a day *for a person who has already become acquainted with the visual appearance of the German script*, even though, as was the case, the German script read had to be written in English. But here again the data are hardly sufficient to carry conviction; *B*, the once-a-day-curve, represents only thirty-one practices divided between five subjects. We had better, therefore, be guided by the comparisons established in Section B.

B. Comparison of the morning with the afternoon gains. The first column of the following table gives in per cents. the average gains made in the afternoon when compared with the

morning's practices. The second column gives the gain of the morning over the preceding afternoon's periods.

AVERAGE INDIVIDUAL GAINS IN PER CENTS.

Subjects.	Writing.		Reading.	
Group A.	After Morning Interval.	After Night Interval.	After Morning Interval.	After Night Interval.
1	2.5	4.7	−0.3	6.7
2	2.7	3.6		
3	2.6	8.3	—2.5	15.7
4	2.1	6.1	—2.3	13
5	0.86	6.8	—2.6	8.1
6	3.5	4.2	2.5	3.9
Group B.	Reading.		Writing.	
29	2.3	15	4.9	1.1
30	2.06	9.7	3.9	7.8
31	15.5	16.9	4.6	3.2

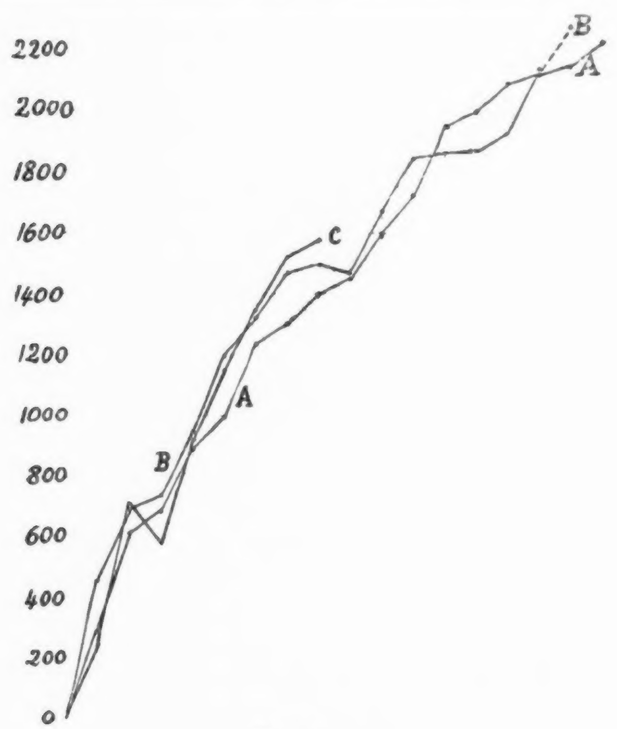


CHART 4.

Group B. Average curves (Reading)

An interval of about four hours, filled with varied intellectual work and much taking of lecture notes, had elapsed between the morning and the afternoon exercise, while twenty hours, including the night's rest, separated the morning from the preceding afternoon's practice. In every case, except in the writing of 29 and of 31, a gain, usually a considerable gain, is

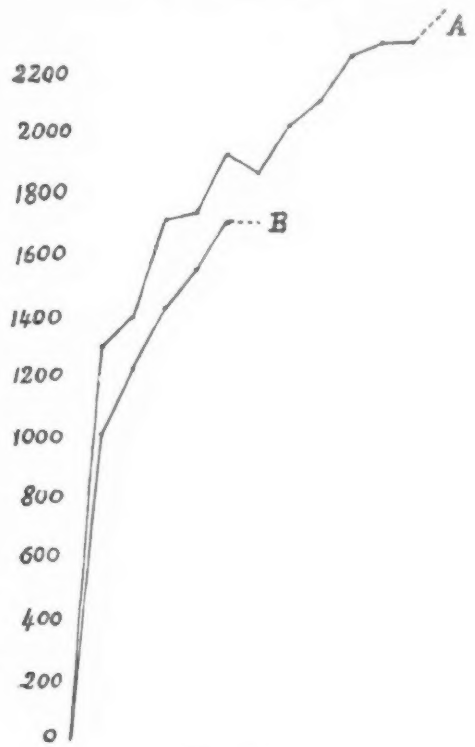


CHART 5.

Group A. Average curves (Reading)

shown in the morning and only a smaller one and, at times, a positive loss, appears in the afternoon. In the reading of four out of six subjects of Group A there is an absolute loss in the afternoon.

What portion of the fatigue so clearly shown in the afternoon's work is to be charged to the morning's practice and what to the intellectual work and to the note-taking of the

students during the four intervening hours? This query is answered convincingly by the fact that the practice of the subjects who show the most rapid progress — once-a-day subjects — was done at 1.40 P. M., except in the case of 7, who did her work at 8.40 A. M. But the curve of 7 was left out of the average curve because she had had some previous practice. Had the single daily practice taken place in the morning instead of in the afternoon, the superiority of the once-a-day curve would have been still greater.

The morning practice and not the students' ordinary morning's work is, it appears, chiefly responsible for the decline in the work done in the afternoon by twice-a-day subjects.

It is to be observed that the afternoon's loss is even more evident in the reading than in the writing. It may well be assumed that it would not have been so if, when reading, the subjects had not had to write in English what they read in German. This seems indicated by a comparison of the reading figures in Group A with those of Group B. In Group A the reading came at the end of the writing practice and the number of letters written in English script was therefore from the start throughout much greater than for the subjects of Group B, who began with reading. This would lead one to expect a greater loss in the afternoon reading of Group A than in that of Group B. That is precisely what the figures show.

The conclusions drawn above are thus confirmed by a comparison of the morning with the afternoon's work and we may consider it demonstrated that for persons of the age of our subjects, intent upon doing the most possible in twenty minutes' time, one practice a day yields the best results in learning to write German script or any other similar script.

Whether shortening the practice period to fifteen or to ten minutes would lead to another result remains an open question.

The bearing of this conclusion upon the length and frequency of the writing lessons of school children is indefinite since they take their work much more leisurely than our students did, and since, being much younger, they tire sooner. For the rest, we do not know that anywhere school children have two writing lessons a day.

Some additional information on fatigue will find place at the end of the next and final section of this paper.

IV. *Comparison of the Amount of Work Done During the Successive Five-minutes of the Twenty-minute Periods.*

The marked oscillations in effectiveness observable in a period of work of twenty minutes' duration are functions of many independent variables, fatigue, ennui, excitability, 'entrainement,' etc.[1] These factors themselves vary, of course, from day to day with the general condition of the subject which, in its turn, depends upon a complicated network of causes.

Out of eleven subjects who practiced twice a day, only two show in their averages an uninterrupted progress from the beginning to the end of the practice: No. 6 with the writing averages, 10,803, 10,816, 10,991, 11,062, and No. 31 with the reading averages, 6,700, 6,861, 6,868, 7,132 and the writing averages, 7,223, 7,367, 7,400, 7,530. The other members of this class show a drop in the second, or in the third and sometimes in both the second and the third five-minute. The best marked instance of this form of periodicity is found in the reading of No. 27 whose averages are 7,903, 7,635, 7,759, 8,466. In all but three averages of these eleven subjects, the last figure is the highest. In these three exceptional cases, the amount of work done during the first five-minute is never equalled in the rest of the practice. In general, one may say that there is a decrease in efficiency in the second five-minute, a recovery in the third five-minute and an additional increase in the last.

But these figures cannot be taken as a satisfactory basis for the measurement of fatigue, since there are several other factors which affect one's productivity. Ennui, excitability, 'entrainement,' each play a rôle in determining the periodicity of these figures. So do also the gains in skill. These gains would, of course, tend to increase the figures as one passes from the first to the last five minutes of each period and therefore would partly mask the effect of fatigue. A more or less definite idea of the extent to which this takes place may be gained from the con-

[1] See, concerning these factors, the excellent work of Lindley, 'Ueber Arbeit u. Ruhe,' *Psy. Arb.*, III., Heft. 3, pp. 482–534.

sideration of the records of Nos. 1 and 3. The total figures for the successive five minutes are:

No. 3	7,493	7,228	7,538	7,309
No. 1	11,901	11,645	11,616	11,670

Comparing the first with the last column, we find a loss for No. 3 of 184 letters and for No. 1 of 231 letters. And yet these two persons gained greatly in skill during the course of the experiment, as is shown by the number of letters they wrote during the last twenty-minute period when compared with what they accomplished during the first:

No. 3	first period	150	last period	1,570
No. 1	" "	450	" "	1,710

A probably valid reconciliation of these apparently contradictory figures lies in the admission that as the twenty-minute proceed, increasing fatigue conceals the increasing skill. The gains, therefore, do not appear in a comparison of the first with the last part of any one period, or of all of them together, as is done in the above figures, but in the comparison of any part of a period with the corresponding part of any subsequent period, or in the comparison of the twenty-minute periods considered in their entirety.

The case of the subjects who practiced once a day only, confirms the foregoing observation on fatigue. Out of six subjects who wrote once a day four show an uninterrupted gain in the successive five minutes; and out of five subjects who read once a day two fall in the same class, whereas, we found only two similar cases among the eleven twice-a-day subjects.

The gain factor is eliminated from the following figures which represent the number of letters written in English from *English* prose. Gains due to increased skill could hardly be expected in the course of a twenty-minute exercise in English writing, since it is constantly practiced by students. The first line gives the averages from the 27 of our subjects who were submitted to the test of writing in English from English copy as fast as they could for twenty minutes. The two other lines are two individual records.

Average	622	613	628	625
Individual	883	762	794	740
"	528	500	565	565

In these English tests the first figure is frequently the highest; only in a small number of cases is the last the highest, although there is no doubt that the subjects made special efforts (excitability, *entrainement*) to surpass themselves in the last part of the twenty minute period. The third period gives the highest average.

The rough general interpretation one may give of these more or less regular fluctuations is as follows: After the first effort has spent itself, there comes a relaxation due to fatigue and weariness. It is overcome by the desire to do one's best when the signal for the beginning of the third five-minute warns the subject of the approaching end and it would be overcome still more completely during the last five-minute if fatigue had not meanwhile become too great. It should not be overlooked that the announcement of the time every five minutes changed to some extent the natural periodicity.[1]

[1] The MS. of this article was received June 28, '05. — ED.

A STUDY OF THE MOTOR PHENOMENA IN CHOREA.[1]

BY DR. G. M. PARKER,
New York.

It is the purpose of the paper to study the movements observed in chorea. This is done with a complete awareness of the narrow field implied, yet with the intention of developing through this limited objective certain definite though different views of the pathology or psychopathology of chorea. The study is not one involving the basic pathological causes, but it is rather an analysis of its predominant manifestations with the aim of more clearly defining the existent physiological conditions through a psychological and biological interpretation of the motor phenomena.

It will be shown that the choreic movements are not incoordinate in a biological sense; that rather they are reversions to type, which, at an earlier point in the development of the individual and the race, have been highly fit.

It will next be shown that in choreic cases these movements may artificially be produced; that their production will invariably be seen to rest upon an attempted functioning of the higher, more complex motor systems; that these choreic movements, capable of approximate measurement, become the more exaggerated, *pari passu*, with the increasing complexity of movement attempted.

Finally, that this implicit relationship develops the conception of a motor hierarchy in which the more complex movements are compounded from the more simple; that, in chorea, there is an inhibition of the functioning of the higher motor systems with the resultant of movements called by Janet 'derivative,'

[1] The contents of this paper is based upon cases studied in the Neurological Department of Vanderbilt Clinic under Dr. Starr, the experimental work having been done in the department of Physiology by permission of Dr. Curtis and Dr. Lee.

movements primal, simple, fixed, but which, early in the developmental scale, have been the component parts out of which the higher types have been evolved and into which the higher is again resolved under certain pathological conditions represented in chorea.

The necessities of this demonstration although few are absolute. There must first be gathered observations of choreic cases as they spontaneously present; the varying and divergent motor elements must be shown as related by common characters and possible of subsumption under wider generalizations. Following this, coördinate with it, must succeed observations derived from cases artificially varied by experimentation, tending thus to throw into relief with clearer outlines the foregoing elements and their relations. Third, these spontaneous and artificially produced phenomena, these inductions must be shown as necessitating a single definite hypothesis.

I. The movements of the choreic child are said to be incoordinate, quantitatively in excess, qualitatively unfit. The fundamental point is the unfitness. In a chronological sequence the early choreic movements fall under a type which is designated as coaptive; the child is to be seen rubbing his fingers one against the other, passing them over the palm of his hand, snapping them together, touching with them different objects in what seems to be a useless, idle manner; his feet, his toes can be noted in analogous attitudes and movements; his tongue, his lips are in constant contact, the tongue being passed over the lips in and out of the mouth, the lips being pressed or rubbed together in a varied and bizarre series of movements. In the constant maintenance and variation of sensory contact of different approximating sensory surfaces is to be found the necessity for the term 'coaptive.'

Even in these coaptive movements the tendency is toward grossness rather than fineness; as the symptoms progress the former is more regularly observed. The movements are quantitatively in excess; they are gross, but they are especially gross because they involve the larger muscular groups and joints in the progress of the disease. The sudden swing of the arm or leg, the bending at the waist, the inclination of the head, the

sudden transposition of the entire body are essentially large movements; large in type as well as large quantitatively. The small fine type movement does not present in chorea save at the terminals.

These movements show further a tendency toward bilateral action. This is not literal, but relative; that the left leg swings violently does not imply an equally wide excursion of the right, but the right leg relatively often would move though not so violently; in the arm it is more constant, the excursion of the minor arm not being an exact verisimilitude of the major, but approximating to it. Facially it is even more noticeable, the grimace being either simultaneously or successively bilateral.

The choreic movements are not single; they tend to repeat themselves or variants of themselves rapidly and persistently, especially if non-interference be advised. The coaptive movements repeat time after time; they change much less abruptly than is apparent, for between two apparently divergent movements there have been interpolated several repetitive series. The gross movements have often been observed as occurring and recurring in series: the child stamps not once, but several times; her body bends again and again; she inclines her head rapidly; there is repetition in all the movements and at all stages of the disease.

Beyond these several purely motor phenomena are to be found a series which, in comparison, are more complex, more organized, and apparently more coördinate because more fit. They differ from the preceding because the end seems partially purposive, though none the less quantitatively the reaction be excessive. The child is seen to leap, to bound, to jump over obstacles, run with enormous strides, or with an uneven speed, varying from immobility to rapid transit. Within the confines of the room, his acts are doubly exaggerated; he leaps over chairs, slams the door with violence, often moves the furniture in the room, particularly those pieces the disturbance of which produces the most noise, throws light objects about, nothing delighting him more than thus pushing or throwing; he strikes suddenly, not viciously or continuously; the mother says he is rough, loud and disturbing; that he cannot remain quiet; if a

girl, that she has become a hoyden; that she no longer plays with the girls, but seeks the rougher sports of the boy. Yet in these the intelligent parent never sees exuberance. Although the acts are purposive, they are not such as to fall within the accustomed habitude of the child; they are not 'fit' for him.

To determine the signification of this unfitness necessitates a return to the question of coördination in this specific type of cases. Broadly speaking coördination connotes a reaction, an adjustment, an adaptation between two factors; namely, the individual at that particular developmental point and that individual's environment, which means, of course, nothing more than the most fit adjustment between the internal and the external.

Coördination is the most fit adjustment. If we adhere rigidly to this, there is nought else for it except that choreic movements are not coördinate. Yet we are not absolutely transfixed in this dilemma. We have said that coördination is the most fit adjustment with due regard to the developmental stage of the individual, the internal factor in its relation to the environment. A reaction which is fit for a two-year-old child is coördinate, yet this same reaction would be unfit, hence incoördinate for one six years old.

Is there possible then in chorea a technical evasion of the law? Are there here motor phenomena belonging to an earlier phylogenetic stage, with the consequent characteristics and their unfitness or incoördination for the present stage?

The coaptive type of movement is one of earliest life; they are the avenues of knowledge as to the material Ego; they are the sensory stuff from which the earliest nucleus of the personality is formed. The babe is seen slowly, discursively passing his fingers over the hand, slowly moving his toes, protruding his tongue, approximating his legs, rubbing his hands over the body in such a manner as to combine the greatest touch area with the greatest kinæsthetic excursion. These movements are present for many months; their appearance is relatively constant in point of development; their transition into reactions to the environment is gradual. They, as coaptive movements, as the first contribution to the ego, are primal, necessary, fit.

Though they be awkward, crude, irregular, superficially non-purposive, yet they are fit — for a definite period of development.

Grossness in movement is displayed early in the child's life in its varied reactions to the external environment. The coaptive movements of the hand while small are never fine; they affect the entire finger, not the terminal phalanx; the excursions are as wide as the function of the joint will permit. It is continually noted that small movements are difficult; that motion involving the large joints presents far more frequently than that involving the smaller; that this relative predominance persists to a much later stage of the child's life than is supposed; that much of the old pedagogical knowledge and kindergarten work has been revised upon these and analogous lines; that finally, the gross movement is that movement which to the individual at an early developmental stage has been and is most fit.

The bilateral movement is never outgrown; in childhood it is everywhere to be seen. The reason for its being is most apparent; the reason for its especial fitness at early life is purely biological; it is fit; hence it presents.

The repetitive movement, the circular reaction of Baldwin, is most important to the individual in his early life. It is the repetitive movement, the incessant repeating which allows of those sudden variations, not *de novo* changes, from which in turn spring the new movement. It is seen in every act; practically no act is single in the child or babe; he repeats and repeats; imitates his own act until there is a chance variation, when, in a second this variation is repeated in a series as was the first. Its importance is enormous; its fixation as a biological stage is absolute; it is seen in all grades of mind and until a relatively late stage of development. It seems non-purposive, yet it is fit to the highest degree — during a certain developmental epoch.

Those movements which have been described as more com plex, more purposive, yet mal-adapted may well fall within that type which Groos in his *Play of Man* describes as the play movement. Groos in this work from which much has been

drawn, develops the biological necessity of play for man. In the earlier bizarre jumping, leaping, throwing, thrusting, rough play he sees that which was of service to the race at an early epoch and now which tends to occur at constant periods of life. If unrestrained, untrained, the ordinary child is usually something of a savage; he does not walk, he bounds; his speech is loud and insistent; he delights to throw rocks, to strike, to push, to thrust. To feel the activity of life, sensory and motor, is to him the summum bonum. Yet all this is fit for a certain developmental epoch. Their advent is not viewed as pathological by rational parents, be the manifestations ever so disagreeable, disturbing.

Resolved thus into their elements the choreic movements appear differently. They are incoördinate for the particular developmental point at which they appear in the specific case. They are no longer fit reactions. But, biologically viewed, these same movements have at an earlier phylogenetic point been highly fit, highly adaptive, hence under the broad acceptation of the term highly coördinate.

II. Beyond, however, this interrelation, this interconnection with earlier phylogenetic series we have not progressed. We have but shown that choreic movements may be resolved into elementary movements, which, in the history of the individual should find themselves at an earlier stage. How these reversionary types present is next to be considered. It can readily be said that they present because they are possible alone, else the higher, more fit, would appear, as it is always the more fit adaption which persists if conditions permit.

Can we show that these lower organized movements are more attainable or, expressed negatively, can we show that the higher combinations are less possible to attain and upon attempted functioning are productive of widely diffusive motor phenomena, which phenomena are those of low and simple organization. If this can be shown, namely that the choreic movements, movements proven to be of low type, reversionary, are produced because of the impossibility of higher functioning, the functioning of more complex systems, are in other words, quoting Janet, 'motor derivatives,' diffuse motor phenomena, then the train of causative sequences will be further advanced.

The main point here, namely, this tendency towards motor diffusion or motor derivatives upon attempted functioning of higher systems requires notice, as upon this line the experments were based. A movement can never be absolutely simple; there is always more or less diffusion into other channels. Movements which are simple, which are thoroughly organized, which are fixed, are those in which the motor portion of the arc is most definite; there is here less diffusion into collateral channels. Movements, however, which are complex, which are highly rather than thoroughly organized, which are not fixed but are rather continuously displaying variation are those movements in which the motor arc is indefinite, not fixed, hence here we have a tendency towards diffusion into collateral channels or systems, and especially into those systems representing that earlier, simpler, more fixed combination from which the more complex has been builded. In chorea the extension of this physiological tendency beyond normal physiological limits into the realm of the pathological affords the *raison d'etre* of the experimental work.

The line of experimentation can herewith be seen. The patient must be made to perform a series of movements, graduated from simplicity and low organization to complexity, all of which movements must fall within the line marked out for the individual by the study of the normal, within general developmental boundary lines. During this experimentation, it must be so arranged that measurements can be made of certain of the most simple and fundamental movements, which movements in their rise and fall may indicate definitely the degree of motor diffusion.

Taking this measureable motor diffusion, then, as an index, we may in turn measure the degree of functioning possible in the different motor coördinations performed by the subject under experimentation. Let the functioning necessary to a certain motor performance become more difficult, less possible to attain by a particular individual, then the curve of his motor derivative will display this in its increased irregularity, its grossness and other characteristics later to be noted. Measure this curve against that of the normal child at the same age and developmental

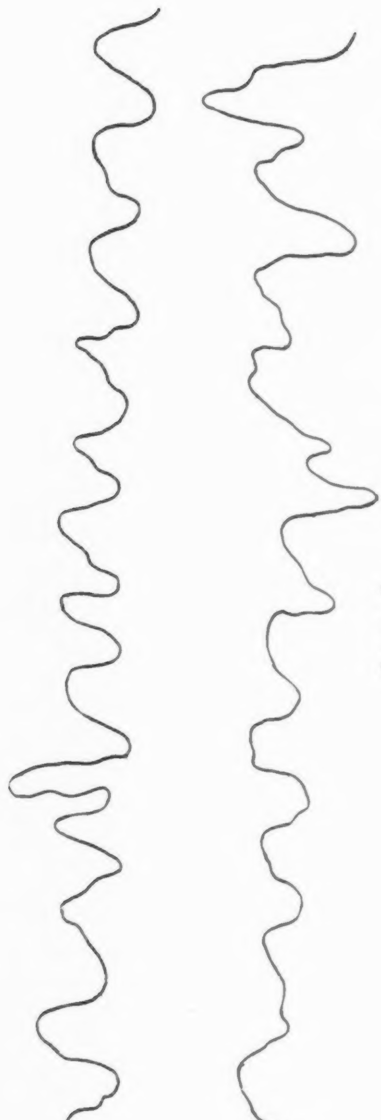
point of the subject, and there will be obtained the proof of the abnormal character of the subject's curve. Further, with this determination one should have a fair measure of the psychological change in his functioning, as well as the meaning in terms of psychology, of the presentation of the involuntary, incoördinate phenomena observed in chorea and analyzed in part one.

For the purpose of the measurements above referred to, the respiratory tracing was selected as presenting the readiest and most accurate curve of a motility phenomenon, simple, primitive and fixed in the developmental scale, and as one which presents invariably in any motor diffusion or presentation of lower phenomena. Hence it can be called a constant and as such a fairly accurate index.

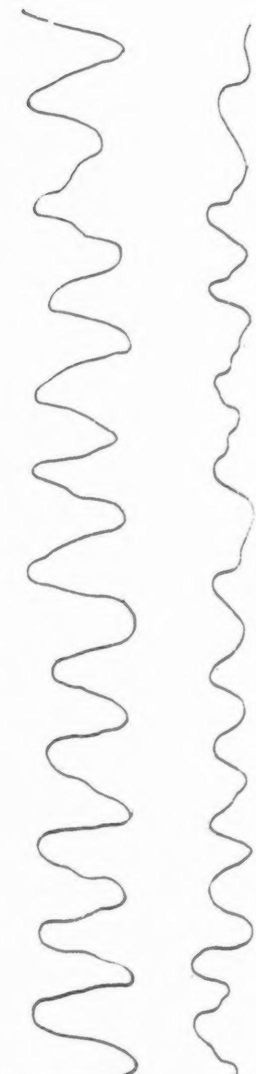
The age of cases experimented upon ranged from five to ten or twelve years. Mentally they averaged well; no deficiency noted in any form; all were clinic cases, but cases from families of the respectable and self-respecting poor among whom the children are not carelessly raised. The work was done in a quiet undisturbed environment. A certain degree of fear, initially present was permitted to subside before beginning work.

With the respiratory belt over the thorax, cases were started upon movements. The movements were subject to considerable modification during the course of the work, it proving necessary in every case to lower the grade of the movement below the mean average. The series were finally ranged in a manner such as to begin with the simple coaptive type, thence passing through several gradations to the circular reactive type, thence to the definitely imitative type seen in copying from the flat in a series of increasingly complex lines, angles and figures, finally arriving at what might be called the constructive type, that of the drawing and formation of idealized figures. Through this necessarily crude series, it will be seen that movements of low organization gradually give place to those of higher. The tracings will be presented pursuant to this general schema.

In tracing *A*, Series I., there is seen the respiratory curve accompanying the horizontal type of coaptive movement. This



SERIES I.



SERIES II.

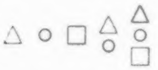
horizontal movement is one of the simplest; it contains the rudiments of the first movements of acquisition and defence. Expressed graphically it is thus $\equiv$. It forms the basis of the earliest variants. In this movement the babe is earliest seen to display its motility, and from this, viewed as a circular reaction type, are derived numerous other movements. There is noted here but relatively slight disturbances of the curve.

Immediately below this curve, however, is placed another accompanying the vertical type of movement, tracing *B*. This movement, vertical in form, performed in a line parallel to the axis of the body, becomes useful and fit at a much later stage than does the horizontal. These curves, obtained from a single source under similar conditions, are widely different. Curve *B* shows the motor diffusion as represented by sudden, deep prolonged inspiration with exaggerated intervals between inspiration and expiration, all so charted as to appear typical only of an agitated respiration. Certain accompanying motor phenomena common to this and other diffuse phenomena to follow will later be considered.

In a way the motor phenomena thus far expressed and performed by the patient might well fall within the type of the circular reaction, *i. e.*, one movement grossly reduplicating itself, notwithstanding the fact that these two movements, horizontal and vertical, were so different in general results. In order to express more clearly this circular reaction with a movement commonly easy, the general form of recurring circle was used, thus combined with a horizontal excursion spatially.

The Curve *a*, Series II., accompanying this, is herewith shown. It is seen to correspond in general regularity of excursion to that of the horizontal in Curve *a*, Series I. It thus appears that the circular reaction presents the characteristics of a simple, lowly organized motor phenomenon.

For contrast there is juxtaposed (Curve *B*), Series II., a curve taken from the same patient under similar conditions, the motor performance alone being varied. This consisted in drawing in the flat: *i. e.*, in drawing of two dimensions, length and breadth but no depth. This drawing was imitative copying from model given, the model being simple, thus:

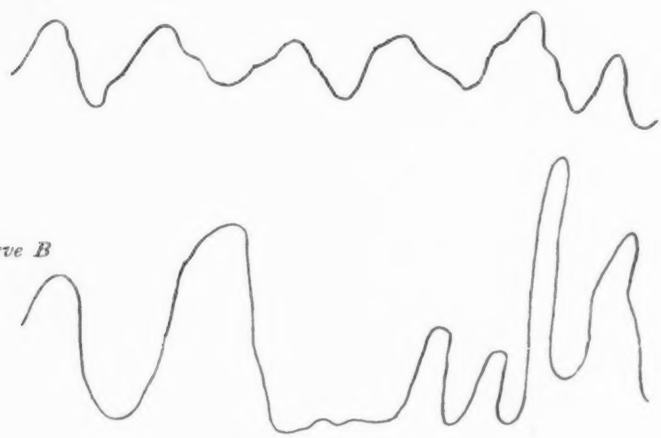


Simple though it be, the necessity for coördinate movement, the motor arc of which must proceed through definite and highly organized systems, was productive of the motor diffusion below graphically displayed.

A third series (Curve 3, *a* and *b*) from another case is next presented, in which the motor performance is precisely similar, but in which the motor diffusion seen in the copying from the

Curve A

Curve B



SERIES III.

flat is far more pronounced. We have here a further corroboration as to the general viewpoint. This series was performed by a child two years younger in age and educational development than the preceding. Drawing in the flat to this child normally implied a more difficult coördination, yet normally falling well within her developmental range. It represented for her a higher relative degree of functioning than for individual preceding; it was hence more difficult, less possible, with motor diffusion more pronounced and wider.

Series IV., Curve (*a* and *b*) further illustrates this point. Here Curve *A* is one accompanying a drawing on the flat as in the preceding. In Curve *B*, however, the patient has not drawn

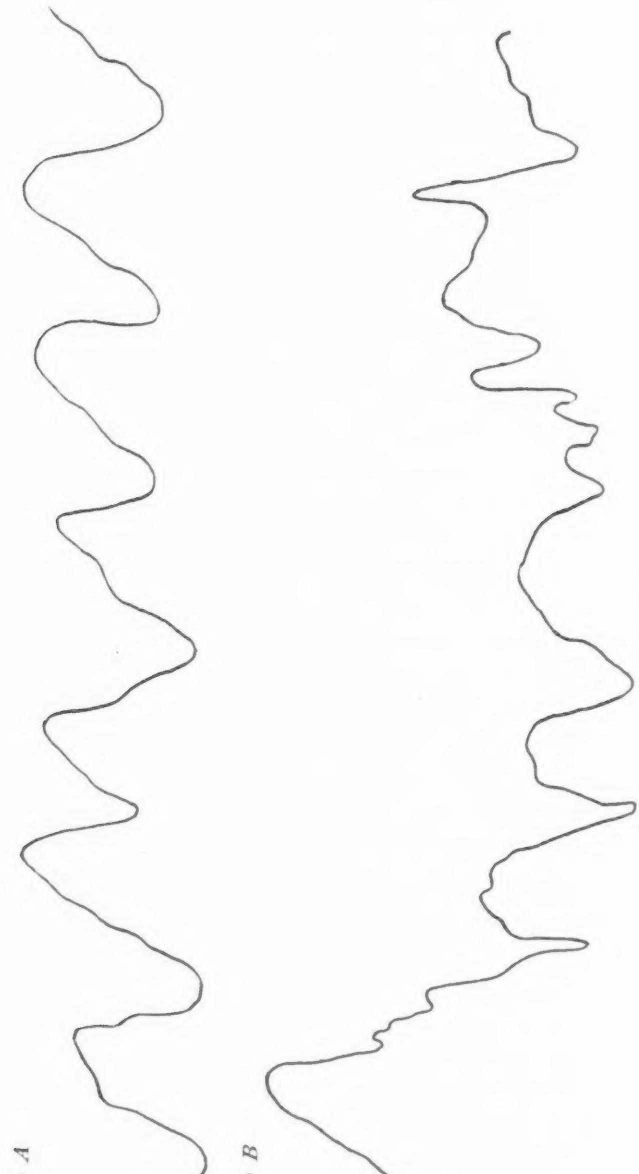
from a copy, imitatively, but has rather carried out the lines of a familiar object, not then in his range of vision; he has ideally constructed a copy, a performance involving wider and more complex systems than the former, hence phylogenetically more recently fixed than those preceding.

It is as well to be noted that, in series with which we have already had to do, Curve *A*, Series IV., is much more regular than Curve *B* in Series III., to which it corresponds. This follows from the age of patient in Series IV., to whom the flat drawing fell far within the ordinary developmental range. He had been so long trained as to render the motor arc fixed, coördinate and fit. To this same child, as we have seen, the idealized drawing, although again falling within his developmental range, yet necessitated a functioning of systems in a way different. Here in the latter there were no sensory fields, no persistent centripetal sensations with a correspondingly limited motor arc as in the former, the drawing from the flat; there was merely representative sensory content with its less defined systems through which the motor impulse proceeded. The absence of constant sensory corrective, the indefinite limitation and the greater variability of the motor arc, all these make for a more highly organized degree of functioning, a more complex degree of functioning. The motor diffusion, the motor derivatives hereby result as shown in Curve *B*.

In no one of the cases does the respiratory curve represent any more than a mere part of the motor diffusion which was evidenced but not grapically reproducible in the sudden gross movements of body, legs, arms, the coaptive series seen in the movements of the hands, the feet, tongue and lips, and other numerous motor derivatives.

In no case, wherein the curve displayed the marked motor diffusion, was the experimental act well performed; it was performed not only with difficulty but most imperfectly.

The result of the experimentation may be briefly subsumed; that in the choreic subject, motor functions, normally falling within the developmental range of the child, were here, first, produced imperfectly; second, their production gave rise to a series of phenomena characterized by a wide motor diffusion



SERIES IV.

into systems whose motor equivalents consisted of primitive simple, early placed reactions, part of which, graphically measureable, is here presented, part of which, impossible to measure, is descriptively added; that the motor functions productive of these phenomena are regularly and invariably those in which the motor portion of the arc is most highly organized, with larger collateral channels, greater variability, hence expressing a finer, higher adjustment to the environment; that, contrariwise, the phylogenetically simple fixed movements are produced readily, perfectly, with no accompanying motor derivatives.

Correlating now parts 1 and 2, it has been seen that, in chorea, those movements spontaneously present, which, from a viewpoint of biology, are to be considered as simple, primitive, if of low organization; which, furthermore, have subserved a useful part in the history of the individual, have been fit at a certain developmental stage.

Experimentally we have produced phenomena similar to the spontaneous choreic movement by the imposition of definite conditions upon the patient. These conditions have been comprehended within the performance of certain complex acts. These acts, falling well within the normal range, have been seen as less possible to the choreic, less perfectly performed, and invariably productive of the phenomena above remarked.

III. Thus far the phenomena have been described, the conditions rendered exact, but explanation beyond this has not been given. In chorea, why does the production or attempt at production of motor acts of high order produce or tend to produce these motor phenomena of low order which present as the most striking symptom of chorea? By the use of the terms 'high' and 'low' order, there has been implied a gradation of motor function.

This gradation psychology terms the motor hierarchy; its ramifications, its limits have been mapped out and determined from many viewpoints. Its content is that which has been epitomized in the choreic case; a series of motor reactions ranging from the most simple to the most complex. Its organization is a series of interrelations. The hierarchy is not additive, *i. e.*, it has not been formed by the mere addition of one

movement to an earlier movement; it is rather a true organized hierarchy in that each movement higher has developed from a variant of an earlier and lower type. It will be recalled that the circular reaction of Baldwin was of that type from which the variant springs, which more and more frequently recurs, then gradually assumes the circular type itself in the perfectioning, and in its turn affords the 'motor platform' from which another variant arises. With an increasing necessity of more fit reactions to the environment, these variants are more determined towards complexity, until the motor functions of high rank are complex and coördinate to an extent of which we have no fair appreciation. This we fail to see, because, in their performance, it is but the end term of the reaction which we perceive and of which we are conscious. Yet, because the component elements of these highly coördinate and complex movements lie below the threshold, because they are the penumbra of the focal motor phenomenon, they cannot be denied. They are demonstrable beyond question in the normal, as myographic tracings have repeatedly shown the presence of the earlier elementary types in the functioning of complex movements.

Now let this complex act be unattainable or with difficulty attainable, then will follow that which lies at the basis of Janet's law of psychological derivatives. This law is as follows: When a force, originally intended to be used for the production of a certain phenomenon, remains unused (for this specific purpose) because this phenomenon has become unattainable, then there are produced derivative phenomena, *i. e.*, the force expends itself in producing other phenomena incoördinate and useless.

We, however, go further in showing that the derivative phenomena are elementary, primitive types of movement which, in the motor hierarchy, have been gradually integrated into higher and more complex systems, have existed beneath the threshold of consciousness and in their spontaneous presentation here as choreic movements, apparently incoördinate, unfit, involuntary, are to be considered as the elements out of which the higher movements have evolved.

We are, thus, not forced to the conception of the overflow

of neuron energy into other and diverse channels, with all the indefiniteness which this conception of 'overflow' implies. It is needful only to view the motor neurons as functioning in systems, which, in the history of the individual gradually increase in complexity of organization as necessitated by the reaction to an increasingly complex environment.

These neuron systems are complex because they are integrated from earlier and more simple neuron systems. This complexity makes for variability and as potentially they become more variable, in proportion they become less stable. Further their functioning, as a complex system, necessarily implies a greater neuron activity or energy than do the lower systems.

If then, by reason of their potential variability, they be more unstable, and if, from any cause there be an insufficient neuron activity in the functioning of these systems, then this neuron activity, insufficient for higher functioning, tends to function the lower elements of these unstable systems with the production of motor equivalents of a correspondingly low order, which motor equivalents, in their mal-adaptation to the environment, in their involuntary character, present those characteristics observed in chorea.

Thus, whatever be the fundamental pathological cause of chorea, it is not simply a cortical irritation; rather the pathology is one which distinctly concerns the motor neurons as systems. That the results of the pathological process are not displayed as irritative neuron discharge; that rather analysis has shown them to be such as would result from the inhibition of the physiological functioning of higher systems, coincident with a hyperfunctioning of the motor neuron systems subordinate to the higher, from which the higher has been evolved and integrated.[1]

[1] The MS. of this article was received June 3, '05.—ED.

STUDIES FROM THE PSYCHOLOGICAL LABORATORY OF MOUNT HOLYOKE COLLEGE.

COMMUNICATED BY HELEN B. THOMPSON.

The Effect of the Brightness of Background on the Extent of the Color Fields and on the Color Tone in Peripheral Vision.[1]

BY GRACE MAXWELL FERNALD.

I. Preliminary Remarks.

Although considerable work has been done on the color-vision of the peripheral portions of the retina, its purpose has been, in almost every case, the determination of the relative size of the various color fields, and incidentally of the characteristic changes which take place in most colors as they pass from the center of the field of vision to its outer limits.

Any discussion of the work done with spectral colors in a dark room may be omitted here as irrelevant, since by this method there is no chance for change of background without introducing illumination of some sort.

The work which has been carried out by daylight falls naturally into two classes, one in which the results have gone to prove the coincidence of certain fields according to the Hering hypothesis, and another in which they have pointed to exactly the opposite conclusions. The two most recent and thorough investigations, those of Hess and Kirschmann, represent the two extremes — Hess[2] found the limits for blue very nearly coincident with those for yellow and the limits for green

[1] The greater part of the work reported in this paper was done in the psychological laboratory of Mount Holyoke College during the year 1903–4, but some additional tests have been made in the laboratory of Bryn Mawr College. I am indebted to Professor James H. Leuba, of Bryn Mawr College, for many valuable suggestions and criticisms.

[2] Hess, C., 'Ueber den Farbensinn bei indirectem Sehen, *Graefe's Archiv f. Ophthalmologie*, XXXV., 4, 1899.

very nearly the same as those for red, while Kirschmann[1] found no such correspondence.

The difference in results in the two cases might easily be due to the great difference in the conditions under which the experiments were performed. Hess worked with colors of equal saturation and brightness and insisted that the background must match the colors in brightness. While the eye followed a small moving fixation point the color was exposed at intervals.

Like Hess, Kirschmann used the campimeter method to avoid the unevenness of illumination, which is found with the perimeter. His campimeter consisted of a vertical strip which was set up so that the stationary fixation point at its center was on a level with the eye of the observer. The fixation point was a square whose side measured 5 mm. The head position was determined only by means of a screen fastened up in front of the vertical strip of the campimeter. This screen had two openings into which the eye and nose of the observer fitted. Thus, to some extent, eye and head movement were allowed. Kirschmann claims that this is not as serious a matter as the exhaustion caused by a more rigid holding of the fixation point, and the discomfort due to a close fitting head rest. He minimizes the possibilities of error by having a considerable distance between the eye of the observer and the fixation point. Hellpack discredits entirely Kirschmann's attempt to calculate exactly the amount of the error which could possibly be caused by eye movement and points out the fact that there was little more reason to believe that the eye would keep within wider bounds than within narrower ones.[2] In fact, it would be even easier unconsciously to move the eye beyond the limits than where the fixation point was so small that any movement could easily be detected.

The color, instead of the fixation point, was moved along the line of the campimeter. Kirschmann considers any error due to change in size of the retinal image because of the increasing distance of the object from the eye, less than that

[1] Kirschman, 'Die Farbenempfindung im indirecten Sehen,' *Philos. Stud.*, VIII., pp. 592–614.

[2] 'Die Farbenwahrnehmung im indirecten Sehen,' *Philos. Studien*, Vol. 15, 1899, p. 533.

which would be caused by the strain of eye movement if the eye followed a moving fixation point and says that the amount of the change in size could easily be calculated. (His procedure involves the continued exposure of the color during each test.) He criticizes the method used by Hess because the error due to irregularity and to after-imagery is of such a nature that it cannot be accurately calculated. He admits that in his own work there will be some error due to irregularity of movement and hence to faulty registration. This however he thinks can be remedied to a large extent by practice on the part of the experimenter. He passes over the effect of exhaustion due to continued exposure of the color with the mere mention that at each moment the color falls on a fresh portion of the retina. In reality only a very small part of the whole portion stimulated at any given moment is entirely unexhausted. This fact would not call for consideration if the work were all done in the inner color zone, but in the peripheral regions where there is little sensitiveness to color, slight exhaustion might easily make a decided difference in the extent of the color field or in the tone of the color seen.

An accurate comparison of the limits obtained by Hess and by Kirschmann with those determined in our own work is impossible, because of the disparity in the conditions under which the experiments were performed. Hess used physiologically pure colors of reduced saturation matching each other and the background in brightness, while we used colors of much greater saturations, not always physiologically pure, and very different in brightness. Kirschmann's work differed from ours in three particulars: (1) He used more than one shade of each color, taking his limit as the mean between the various points thus determined. (2) His black background was much darker than our darkest background, so that the only case in which our backgrounds were similar was that in which the white background was used. With the white background only one subject (himself) was experimented upon, so that individual peculiarities may explain the difference in results even with similar backgrounds. (3) As Kirschmann moved the color along the plane surface the difference, between the size of the

retinal image in his experiment and ours, would vary at different points. For instance, in his work with the white background the retinal image would be at least twice as large as ours for the point on the perimeter where green was last seen, and somewhat larger than ours where blue was last seen. Though the difference in size could be calculated for each limit there seems as yet to be no way of accurately estimating the difference in effect due to increase or decrease in the size of the retinal image. These differences in method are mentioned only in order that we may not seem too dogmatically to ascribe the considerable divergences which exist between the limits determined by Kirschmann and those determined in our work, to difference in the method of exposing the color.

The fact that Kirschmann's limits are, in every case, considerably narrower than ours is at least not contradictory to the statement that exhaustion due to continued exposure of the color decreases the size of the retinal color fields, and it is entirely possible that his fields would have been wider had he eliminated this possibility of error.

In class work done here according to the method described in Titchener's *Manual* (pp. 9–11) the students constantly complained that when they started with a fixation point well beyond the limits found for a color by moving the eye out in a centrifugal direction, the color was clearly seen when the fixation point was first taken, and lost only by holding the point an appreciable length of time. Then if the eye was moved in, the color next became perceptible at a point farther in than the one at which it had disappeared in a previous test. Since the difficulty could not be removed by the most careful holding of the fixation point and by constant practice, a series of tests was made to find how far out on the retina it was possible to see colors when there was no retinal exhaustion. To do this a method was devised which did away largely not only with retinal fatigue, but also with eye movement during a test.

The details of the method will be described when we discuss our own experiment. For the present it will be sufficient to say that it consisted essentially in first taking the fixation point and then exposing the color, giving a sufficient rest interval between

tests. The fields determined in this way were considerably wider than any we were able to obtain by a method which involved continued color exposure or eye movement. An additional advantage of the method is that it makes possible a study of the changes which may take place in a color when exposed for any length of time at a given point on the retina.

While both Hess and Kirschmann worked with backgrounds of different brightnesses, neither of them takes up the question of the effect of the background on the color tone.

In the two places where Hess remarks particularly upon the effect of the brightness of background on the color, he makes it very clear that the only changes he considers as taking place are those in brightness and in saturation of the color. After he has enumerated the various alterations which may take place in the color tone of a given color in different portions of the color field, he says (I., p. 7): "In the previous summary notice is purposely taken only of the color tone. The changes in saturation and brightness demand a special discussion. In this respect one and the same pigment color can go through very different changes. For example, in indirect vision, a saturated orange on a black background is seen as bright yellow, while on a white background, it is seen as dirty dark yellow. A given green, moreover, with all other conditions constant, can be seen as dark gray on a white background, as light gray on a black background, and can be entirely invisible on a gray background of a certain brightness."

Later on in stating his reasons for insisting that the white valency of the color and of the background must be the same if the measurements of the color fields are to be accurate, he says that the color is seen farthest out on the periphery when the color and background match in brightness. (I., p. 51.) "In indirect vision, the relation between the white valencies of the color and the background has a decided influence on the perceptibility and upon the disappearance of the color. The color is perceived farthest out when the background is of the same white valency as the color. As the difference between the two white valencies increases, the peripheral color field decreases." He cites as an illustration an experiment in which the limit for

physiological red along the temporal meridian was 27° with a matched background, 19° with a black background, and only 13° with a white background.

Kirschmann, who, as has been stated, worked only with black and white backgrounds, found decided difference in the relative size of the color fields in the two cases. The only qualitative difference mentioned by Kirschmann as directly due to the background is found in the case of yellow and is especially interesting to us. His statement is as follows (II., p. 607): "Our yellow disk, and sometimes even the yellow-green disk, arouses the orange perception on the nasal meridian almost sooner than the orange color itself, since the latter probably loses something through brightness contrast with the white background. Apparently for the same reason the specimens of the lighter less saturated series were frequently recognized sooner than the real representatives of the colors concerned." This peculiar behavior of yellow with the light background is in perfect agreement with our results, though our explanation will be seen to differ decidedly from that given by Kirschmann. We found yellow frequently seen as orange within the limits for orange and often beyond the place where the orange disk itself could be correctly perceived.

As Kirschmann was not testing the difference in the effect of the two opposite backgrounds on the color fields, he varied the conditions with respect to size of retinal image and number of colors used in the two cases, so that we will not attempt to compare the two sets of limits further than to say that with the light background his yellow field is strikingly small on the nasal meridian.

II. Experimental Work.

The purpose of the experiment was to determine (1) the dependence of color tone on the brightness of the background and (2) the variations which take place in the size of the individual fields with backgrounds of different brightnesses. Since no attempt was made to establish the relative size of the fields of different colors, but only to determine the difference in the behavior of one and the same color under different conditions,

it was not necessary to fix an equal standard of saturation and brightness for the various colors used. It was essential, however, that the only changes occurring should be due to the difference in background and not to any other factors. The general conditions of the experiment had, therefore, to be made as constant as possible.

The main sources of error to be avoided were, changes in illumination during a given experiment or from day to day, after-imagery and exhaustion due to the presence of any color beside that used in the experiment, exhaustion due to any other factor, as continued exposure of the color or an uncomfortable position on the part of the observer, and finally the difference in eye position for a given fixation point.

That the illumination might be kept, as far as possible, constant and also that there should be no foreign color effect, the work was all carried out in a room whose walls and woodwork were of a uniform white. The table on which the campimeter stood was covered with a medium gray cloth, and heavy white curtains were arranged at the windows so that they could be lowered on bright days and drawn back on dark days. Care was taken not to work when the illumination was really poor.

The remaining sources of error all have to do with the method of exposing the color and of determining the eye position during the exposure. Authorities differ widely as to the best method — since it seems as if one error is no sooner escaped than another one is introduced.

The methods employed by Hess and Kirschmann have already been briefly described, the difference between these two experimenters being that while Hess used a stationary color exposed only at intervals and a movable fixation point, Kirschmann moved the color along the campimeter and had a stationary fixation point.

The question of error due to difference in head position has never been considered a serious matter, and yet it can readily be seen that with any sort of a head rest, which did not clamp the head into an impossibly uncomfortable position, the head might be so placed at different times that the eye position with reference to the opening of the campimeter or to the color

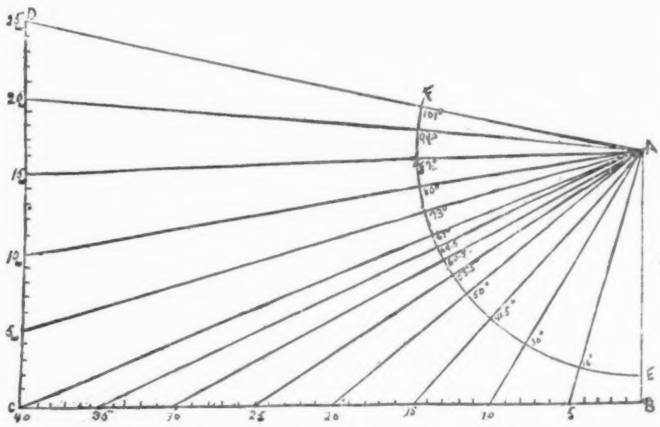
might vary considerably. That is, the angle of the visual axis with the plane of the campimeter might differ at different times and yet the observer have the eye fixed on the same point, so that for a given fixation point the image of the color might fall on different portions of the retina.

The method of the present experiment varied somewhat from those of either Hess or Kirschmann. The apparatus used was a horizontal campimeter. The head was supported on a rest made of lead which was soft enough so that it could be bent to fit the forehead and cheek of the observer, and yet hard enough to keep its shape when once bent. (A different head rest, with an opening on the side toward which the eye turned, was used for each principal meridian.) The rest was firmly supported on iron standards and tested frequently to be sure that it remained at the same distance from the opening. The right eye was used in all the experiments and the left eye was covered with a small black cap which allowed the eye to remain open. Since, in the case of the nasal meridian, no point on a level with the campimeter was found at which all the colors failed to be seen, a vertical strip was attached to the edge of the campimeter farthest from its circular opening at right angles to its horizontal plane. By taking a fixation point on this upright strip the eye could be turned so that the color would fall on the extreme edge of the field of vision. The campimeter readings could readily be transformed into degrees on the retina by some such simple device as that shown on opposite page.

In order to insure constancy in eye position with regard to the color exposed a small square of mirror as near colorless as we could obtain, was placed on the table directly beneath the opening of the campimeter.[1] For each test the observer began with his eye looking directly into the mirror, with the long axis of the opening of the eye in line with the fixation points lengthwise of the campimeter, and then moved it out to the given fixation point. As, at the start, the eye was so placed above the opening of the campimeter that the image of the pupil in the

[1] This mirror was held in position by thumb tacks and leveled before each experiment by means of a circular level. It was also tested at the end of each experiment to make sure that it had not changed level.

mirror appeared equidistant from the sides of the opening, there was little chance for differences in the position of the eye with reference to the color, when the eye had moved to its fixation point. That is the angle between the visual axis and the plane of the campimeter was a right angle when the eye was fixed on its own image in the mirror. For any other given fixation point the acute angle formed between the line of the visual axis and the plane of the campimeter was always the same and the color fell at the same distance from the center of the retina.



A represents eye position, *B* the opening in the campimeter (opening 1.2 cm. in diameter); distance from eye to campimeter 17.2 c.c., and from the cornea to the nodal point of the eye .7 cm. *BC* represents the line on the base of the campimeter and *CD* the line, on the vertical piece, at right angles to *BC*. The divisions on the lines *BC* and *CD* represent divisions of 1 cm. each, and those on the arch *EF* degrees on the retina. Suffix *u* stands for upright.

After the observer had taken the fixation point, the color concealed beneath a gray paper which matched the background in brightness, was slipped over the mirror and the cover quickly removed. As the color was exposed a stop-watch was started, and stopped at a signal from the observer, when the color was gone. The observer, who had no previous knowledge as to what the color was to be, reported what he had seen. An interval of two minutes was allowed before each test, to avoid exhaustion effects.

Now the strongest proofs that the colors seen with the distant fixation points were not due to eye movement, are the results of these experiments. In the first place, at the very outer limits where color was first distinguished, it was generally seen as a dull or, less frequently, as a bright flash of color, often different in color tone from the original stimulus. With the darker backgrounds the various greens and reds, including orange, were first seen as yellow, while, with the light background, orange was seen as a bright flash of pure red. Then, as the color was brought farther in toward the center of vision, the correct color tone began to be seen and a gradually increasing time during which the color was seen, was found. This was too constant to be disregarded. The following readings for orange show the gradual increase in time, and are typical illustrations of the time measurements. The orange exposures were not given in immediate succession as the table seems to indicate, but were separated by considerable intervals in which other colors were tested.

Background No. 7. Color Orange.

Fixation Point.	Color Seen.	Time.
20_u	Chiefly white—perhaps yellow.	
19_u	Very brief flash of yellow.	——
18_u	Brief flash of yellow.	——
15_u	Yellow.	1.2 sec.
14_u	Yellow, slightly orange tinge.	3.2 "
11_u	Yellowish orange.	3.4 "
8_u	" "	4 "
2_u	Orange changed to yellow.	4 "
4_u	Reddish orange.	6 "

(The suffix *u* means that the fixation point was on the upright of the campimeter. The readings are in centimeters.)

The following averages are taken from the preliminary work done with red. The conditions of the experiment were the same as those in the final work except that red was used almost exclusively. This gives a much greater number of readings for each average than could be obtained from our later work.

The index shows in each case the number of readings included in an average. The numbers of the table designate the subjects experimented upon, and in each case refer to the

same subjects as those marked I. and II. in the tables at the end of the paper. An entry 0 means either that the color was not seen or else appeared in a flash too brief to be measured by the stop-watch. The time readings are all in seconds.

SUBJECT NO. I.

Color = Red. Nasal Meridian. Background = Hering Gray Paper No. 17.

	20_u	19_u	18_u	17_u	16_u	15_u	14_u	13_u	12_u	11_u	10_u	9_u	8_u
Not seen.	0^3	0^2	0^2	0?	0?	0^2							
Seen as yellow.	$0'$	0?	0?	$0'$	0^3	0^6	$0'$	1.5^2					
" " orange.				$0'$		0^2	$0'$	1.5^2	1.8^2		3.3^{10}	4.1^5	$2.5'$
" " reddish orange.								1.4^2			$2.8'$		$1.9'$
" " red.										$0'$			

	7_u	6_u	5_u	4_u	3_u	2_u	1_u	40	35	30	20	18
Not seen.												
Seen as yellow.			3.6^2									
" " orange.	5.1^3		4.7^4	$4.2'$				$7'$	5.3^2			
" " reddish orange.		2.6^3	4.3^5	$3.4'$	5.4^2	4.3^3	5.5^2	5.9^4	5.7^5	5.7^5	7.4^2	
" " red.											14?	$10'$

SUBJECT NO. II.

Color = Red. Nasal Meridian. Background = Hering Gray Paper No. 17.

	24_u	23_u	22_u	21_u	20_u	18_u	17_u	16_u	15_u	14_u
Not seen.	0^4	0?	0^2	$0'$	0^2	0^3			0^2	$0'$
Seen as yellow.	0y′	0^4	0^4	0^2	3.5^4	3.5^7	$5'$	4.9^2		
" " orange.	0?		$0'$		0^2	$0'$	$0'$			6.5^3
" " reddish orange.								$3'$		
" " red.				$0'$	0^2			$0'$	0^3	$0'$

	13_u	12_u	11_u	10_u	9_u	8_u	7_u	6_u	5_u	4_u
Not seen.										
Seen as yellow.	11.1^2									
" " orange.		6.9^3	$10.2'$		$10.2'$	$6.8'$	$6'$			
" " reddish orange.		$7.2'$	$7.2'$	5.5^2		6.2	$5.6'$	8.2^2	6.4^2	10.6^2
" " red.	$0'$	$0'$	0^2	2.3^3	0^2	$4.6'$		7.9^2		6.6^2

	3_u	2_u	1_u	40	35	30	20	10
Not seen.								
Seen as yellow.								
" " orange.			$8.2'$					
" " reddish orange.	7.1^3			8.6				
" " red.		8.9^4	$9.6'$		$7.2'$	$11.2'$	$20'$	$28+'$

The results show the gradual increase of the time during which the color is seen as the color moves in from the extreme peripheral regions toward the center of vision. They also show

that, in certain peripheral portions of the retina there are three possibilities for red at the same point — either the true color tone is seen for a briefer time, or else yellow or orange appears and remains for a longer time. It has been found in all the work that there is a strong tendency for a color to last longer at the inner limits of the zone where it is seen as yellow than at the outer limits of the zone where it is seen in its true color tone.

To determine the effect of the brightness of background on color tone, blue, yellow, red, green, and orange have been tested with four different backgrounds. The colors used were the Hering disks (tissue-paper series) representing a fully saturated spectrum. The backgrounds were of Hering gray paper which matched the yellow, the blue, the green, and the red disks in brightness. Arranged according to brightness their order would be — the background for blue, Paper No. 29[1] (a very dark gray); for red, Paper No. 17; for green, Paper No. 7; and for yellow, Paper No. 3 (a very light gray). The method for matching the brightness of the background to the colors was that of exposing the color in the usual way at a point in the periphery beyond the limits of color vision, and determining the brightness at which each color remained entirely invisible when so exposed.

The effect on color tone of a change in the brightness of the background is twofold: (1) It modifies the tone of the color as initially perceived, (2) it affects the change taking place in the color tone as the color fades out.

In the tables at the end of the paper the Arabic numerals represent the color seen when no change in color tone took place as the color disappeared, the Roman numerals represent the color seen when there was a change in color tone during the exposure. In every case except that of green this change is toward yellow. Green, whenever it changed tone, began with a yellow and grew either greenish-yellow or pure green. The Arabic numerals in heavy-faced type mean that no color was seen at the point designated.

[1] Paper No. 34 was found to match better in later tests.

The four persons who have been experimented upon have all had previous training in laboratory work. Two of them, I. and II., knew what results were being obtained, while III. and IV. knew nothing whatever about the experiment or the colors used.[1] The general character of the results differs very little in the two cases.

Only those colors have been worked with which change their tone toward yellow rather than blue in peripheral vision. It will readily be seen that in general the change is toward yellow with the dark background, and toward red or green with the light backgrounds. The following tables summarizing all the results of the final work show the characteristic behavior of the colors:

Nasal Meridian.

Color	Background.	Seen as Red.	As Orange.	As Yellow.	Not Seen.	Total No. Tests.
Red.	For blue.	19 XVII.	16 IX.	10	3	74
"	" red.	37 XIV.	13 VII.	13	14	98
"	" green.	39 I.	3 II.	6	19	70
"	" yellow.	65	4		15	84

Color.	Background.	Seen as Orange.	As Red.	As Yellowish-Orange.	As Yellow.	Not Seen.	Total.
Orange.	For blue.	XXX. 2		XI. 10	31	3	84
"	" red.	VI. 13	II. 15	VIII. 12	28	8	75
"	" green.	XII. 19	II. 100	23	8	8	100
"	" yellow.	24		11	3	16	156

Color.	Background.	Seen as Yellow.	As Orange.	Not Seen.	Total.
Yellow.	For yellow.	88	32	16	132

Color.	Background	Seen as Green.	As Greenish-Yellow.	As Yellow.	Not Seen.	Total.
Green.	For blue.	7	8	15	3	33
"	" red.	13	25	23	14	75
"	" green.	29 III.	20 IX.	30	16	107
"	" yellow.	14 I.		2	29	46

Temporal Meridian.

Color.	Background.	Seen as Red.	As Orange.	As Yellow.	Not Seen.	Total.
Red.	For blue.	13	8 I.		3	25
"	" green.	10 I.	3		5	19
"	" yellow.	21			2	23

[1] IV. was unable to continue the experiment after the readings on the nasal meridian had been taken.

Temporal Meridian.

Color.	Background.	Seen as Orange.	As Red.	As Yellowish-Orange.	As Yellow.	Not Seen.	Total.
Orange.	For blue.	7 XI.		8 VIII.	15	10	57
"	" green.	18 I.	2 I ?	7 I.	8	6	44
"	" yellow.	7 7R.O. (2?)	14 II.(1?)	2 (2?)	4	6	47

Color.	Background.	Seen as Green.	As Greenish-Yellow.	As Yellow.	Not Seen.	Total.
Green.	For blue.	15 V.	5 II. (1?)	14	6	48
"	" green.	10 (1?)	17	1	8	37
"	" yellow.	23 (2?)	3	1	6	35

Upper Meridian.

Color.	Background.	Seen as Red.	As Orange.	As Yellow.	Not Seen.	Total.
Red.	For blue.	20 I.	29	3	3	56
"	" green.	30	9		22	61
"	" yellow.	44			15	59

Color.	Background.	Seen as Orange.	As Red.	As Yellowish-Orange.	As Yellow.	Not Seen.	Total.
Orange.	For blue.	10 V.		6 VII.	16	7	51
"	" green.	42	19	11 I.	10	15	98
"	" yellow.	25	28			8	61

Color.	Background.	Seen as Green.	As Greenish-Yellow.	As Yellow.	Not Seen.	Total.
Green.	For blue.	15 II.	11 II.	14	12	56
"	" green.	10 I.	19 (2?)	13	21	66
"	" yellow.	7	7	2	4	20

Lower Meridian.

Color.	Background.	Seen as Red.	As Orange.	As Yellow.	Not Seen.	Total.
Red.	For blue.	8 I.	15 (1?)	2 1?	2	30
"	" green.	14			12	26
"	" yellow.	6	1 (1?)		4	12

Color.	Background.	Seen as Orange.	As Red.	As Yellowish Orange.	As Yellow.	Not Seen.	Total.
Orange.	For blue.	5 I.		8 III.	5	8	30
"	" green.	17	4	1	2	10	34
"	" yellow.	9	11 II.		1	3	26

Color.	Background.	Seen as Green.	As Greenish-Yellow.	As Yellow.	Not Seen.	Total.
Green.	For blue.	2	5	9	6	22
"	" green.	2	7	7	5	21
"	" yellow.	7 (1?)		1	4	13

Red appears as orange or yellow only with the three darker backgrounds and much less often as one of these colors with the background No. 7 than with the backgrounds No. 17 and No. 29, which are darker. It is also true, with a few exceptions (which occur with the background No. 7), that red changes its color tone toward yellow when seen first as red, only with the two darkest backgrounds. On the background No. 3 it is either not seen, or is seen as red at the same points where it is seen as yellow or orange with the two darker backgrounds.

Orange shows even more clearly than red the effect of change of background. With the two darkest backgrounds it is almost invariably seen as yellow or yellowish orange at the farther fixation points. Even when it is seen as orange at the more central points it fades out as a clear yellow. With the medium background (No. 7) there seems to be a sort of transition stage. That is orange is sometimes seen as orange, sometimes as yellowish-orange and yellow, and sometimes as a very reddish-orange or a pure red when this background is used. With the lightest background orange is oftenest seen as pure red.[1] The color as described by all the observers is 'a good pure red just like the red disk.' It is practically never seen as yellow with this background.

Green is less certain in its behavior and, unfortunately, the readings for green are less complete than those for orange and red. There seems to be a much stronger tendency for green to be seen as yellowish-green and yellow with the three darker backgrounds than with the lighter background. This is certainly the conclusion to which the readings on the nasal and temporal meridian point. Even with the other two meridians, where the proportion of readings for green is small, the results favor the statement just made. The darker backgrounds certainly intensify the yellow in the pigment color more than the lighter backgrounds.

[1] This result is at variance with that of Hess, who affirms that orange looks a 'light yellow' with a dark background and a 'dark yellow' with a light background. He gives only a few results obtained with the black and white background, and most of his work seems to have been done with the medium gray background. This may explain why his results differ from ours.

Yellow is seen as orange only with the background No. 3, and is frequently judged to be orange along all the meridians with this background. It ought to be stated here that the yellow disk used belonged to the older set of Hering disks, and is a somewhat golden yellow though by no means enough so to be called orange.

It would seem, in consideration of the results given above, as if the color most like the background in brightness was the one which tended to be obliterated. With the background for red, and also that for blue, the red fails to have its full effect in determining the color seen, while the yellow, which is farthest from the dark backgrounds in brightness, has its effect in some way heightened by the brightness contrast. Thus beyond the limits for red, orange and green we see a clear, distinct yellow when either the red or green disks are used. With the background for yellow we find red seen only as red, orange with its red factor so intensified and its yellow factor so lessened, that it is often seen as red, and even yellow tends to appear as orange.

The increased activity of yellow with the darker backgrounds and the lessened activity of green and red is seen in the fact that even within the limits for these colors, the yellow factor is predominant either before or after the true color is seen, and the interval during which the true color tone is distinguished is short as compared with that when the lighter backgrounds are used.

If it is true that the color least like the background in brightness is intensified, we would expect to find a decided difference in the width of color fields with a change in the brightness of the background. So far the only fields we have carefully determined are those for blue and yellow on nasal meridian. Tables I. and II. are the results for the same two subjects as those designated in the other charts as I. and II. Subject III. is a graduate student at Bryn Mawr College who knew nothing of the experiment. In the last two cases the darkest background used was No. 34 instead of No. 27, and the medium background was No. 17 instead of No. 7.

The field for yellow is decidedly widened in every case as the background grows darker. This fact seems to agree very well with the qualitative effects of the background on the color.

Limits for Yellow. *Nasal Meridian.* *Limits for Blue.*

Limits for Yellow.

I. Background No. 29.			No. 7.		No. 3.	
Degrees on Retina.	Seen.	Not Seen.	Seen.	Not Seen.	Seen.	Not Seen.
98.5	3	11				
97	3	1[1]				
95.5	3	1				1
94	1			3		4
92.5	2		2?	3 green	1	2
91.5	1		4	1[1]	1	4
90			3		2	1
88.5			1	1	4.1?	[1]
87					1 3 orange 1?	

II. Background No. 34.			No. 17.		No. 3.	
Degrees on Retina.	Seen.	Not Seen.	Seen.	Not Seen.	Seen.	Not Seen.
98.5	1	2		3 1?		4
97	2	2 ⋮ 2?	3	5 ⋮ 1?		7 1?
95.5	7	2[1]	4	3 ⋮ 1?	3	7
94	6 ⋮ 1?	1	6	[1]	1 ⋮ 3?	4 ⋮ 1?
92 5	2		2		4	2[1]
91.5	2				2	2

III. Background No. 34.			No. 3.	
Degrees on Retina.	Seen.	Not Seen.	Seen.	Not Seen.
102.5		4		2
101	4 2?	4	1	6 1?
99.5	7 1?	1 ?[1]	4	9
98.5	6 2?	1	4 4?	3 1?
97	6 1?		7	2 orange 1?
95.5	4		6	4
94	4		2 1?	2

Limits for Blue.

I. Background No. 29.			No. 7.		No. 3.	
Degrees on Retina.	Seen.	Not Seen.	Seen.	Not Seen.	Seen.	Not Seen.
91.5	1	3		4		1
90	1 1?	3		3	1	1
88.5	3 1?	1[1]	1 1?	2	1	3
87	2		4	1[1]	2	
85.5	1		2 1?	1	4	4
84			2		2 1?	5
82.5			3		5 1?	5
81					6	

II. Background No. 34.			No. 17.		No. 3.	
Degrees on Retina.	Seen.	Not Seen.	Seen.	Not Seen.	Seen.	Not Seen.
101						2
99.5					1	1?
98.5		3		3 1?	4?	4[1]
97	1	4 1?	3	4 3?	6 2?	1 1?
95.5	6 1?	4[1]	5	1[1]	4 2?	2
94	6 1?	1? 1	5		9	
92.5	3		2		6	
91.5	2				5	

III. Background No. 34.			No. 3	
Degrees on Retina.	Seen.	Not Seen.	Seen.	Not Seen.
101		3		2
99.5	3	5 1?		6
98.5	2 1?	4 1?	2	6
97	5 2?	1[1]	7 1?	2[1]
95.5	4	1	5 1?	1?
94	2 1?	1	5	1

[1] Indicates the point taken as the limit in each case.

For blue the results are not so conclusive. In table I. blue is seen farther out with the dark background than with the light background. The explanation here might be that the observer evidently has not as keen a perception of blue as of yellow and so is more erratic in the case of blue. It is impossible to tell as the table stands whether the limit with the lightest background would be at 82.5°, at 85.5°, or at 87°. If 87° is the correct limit then the results are not especially disturbing.

In the second table the limits for blue are the same with the two darker backgrounds, but wider with the lighter background. In table III. the limits are exactly the same with the two backgrounds used.

In the work represented by the tables at the end of the paper, the most complete set of results was obtained with orange on the nasal meridian. It will be seen from these results that there is a strong tendency on the part of orange to appear in its true color tone much farther out with the lighter backgrounds than with the darker backgrounds. In those cases in which it is not seen farther out as orange, it is seen farther out as red, which means simply that the red factor is intensified. That is, orange will be seen as *yellow* with the *darker backgrounds* at the same fixation points where it is seen as *red* or *orange* with the lighter backgrounds.

The following table gives the farthest points at which orange was seen as red, orange or yellow with the various backgrounds.

Limits for Orange—Nasal Meridian.

I.

Background No. 29.	Seen as *Orange* to	73°	As *Yellow* to 87°
" " 17.	" "	69.5°	" 92.5°
" " 7.	" "	73°	" 92.5°
" " 3.	" "	84°	As *Red* to 87° (once only as yellow)

II.

Background No. 29.	Seen as *Orange* to	64.5°	As *Yellow* to 94°
" " 17.	" "	60.5°	" 94°
" " 7.	" "	82.5°	{ As *Yellow* to 91.5° / As *Red* to 72°
" " 3.	" "	85.5°	" 91.5°

III.

Background No. 29.	Seen as *Orange* to 72°	As *Yellow* to 91.5°	
" " 17.	" " 78.5°	" 91.5°	
" " 7.	" " 80°	As *Yellow* to 91.5°	As *Red* to 64.5°
" " 3.	" " 82.5°	" 88.5°	

IV.

Background No. 29.	Seen as *Orange* to 67° (once at 87°)	As *Yellow* to 90°
" " 17.	Seen as *Orange* to 64.5°	" 94°
" " 7.	" " 64.5° (once at 87°)	As *Yellow-orange* to 88.5° (once only as yellow); As *Red* to 77° (once only as yellow)
Background No. 3.	Seen as *Orange* to 74.5°	As *Red* to 84° (once only as yellow)

The effect of the brightness of backgrounds on the limits for red and green along the nasal meridians and for all the colors on all the other three meridians cannot as yet be reported upon. Our results are too incomplete to justify any further conclusions. Orange was used more often than the other two colors because of its peculiar interest.

As far as the work has been carried out we seem justified in drawing two conclusions:

1. The brightness of a colorless background has a decided effect on the color tone of any color which is not spectrally pure — that is on any color which is, in the slightest degree a color mixture as is the case with all pigment colors. It appears further that this effect may be due to the intensifying of the component color least like the background and the obliterating of the component color most like the background in brightness.

2. The brightness of the background affects also the width of the color field. In the case of orange and yellow the field is widest when the contrast between the brightness of the color and of the background is greatest. The explanation of this fact with regard to orange must again be based upon the fact that orange is a color mixture, since what seems to occasion the change in size of the orange field is the relative difference in the proportions of the red and yellow factors with the different

backgrounds. The question would ultimately reduce itself to the effect of the background on red and yellow respectively. If orange were taken as one color it would seem that it ought to be distinguished farther out with a very dark background than with a very light background, since in the case of the former background the brightness contrast between color and background is really greater than in the latter case. But if the brightness of the background effects the two components of orange differently, emphasizing in every case the color least like the background in brightness, then the results obtained are in exact agreement with what we should expect. It is possible that further work will show a change in the limits for blue in accord with the principle which seems to apply to yellow and orange, though it scarcely seems probable that the effects will be very pronounced.

We are at present at work on the colors that change their color tone toward blue (*i. e.*, purple, violet, carmine, blue-green and green-blue), and also on the retinal limits of all the colors represented in the Hering disks. The apparatus has been so modified that the mirror is no longer necessary for determining the initial eye position, but the results so far seem to agree with those already reported.

A further point worth mentioning is the fact that, in the case of several colors, exposure, beyond the limits where any color is seen, is followed by a very clear after-image. This was repeatedly found to be true with red, orange, green, and blue and often with yellow. This after-image for the first three and for yellow was blue, and for blue a very clear yellow. This may explain the 'gegen farbige' zone[1] found by Hellpack in his dark-room work, as under those conditions there would have been no way of telling whether the color came exactly at the time of exposure or immediately afterwards.

Explanation of Tables.

The numbers of the tables indicate the subjects, the letters the meridians: (A) nasal, (B) temporal, (C) upper and (D) lower.

Arabic numerals designate color seen without change of tone during exposure.

[1] *Phil. Stud.*, 1899, Vol. 15, p. 536.

Roman numerals designate color seen with change of tone during exposure.

Arabic numerals in heavy-faced type indicate that no color was seen.

To trace the limits for a color it is necessary, first, to find the points where no color was seen, then where it is seen in other color tones than its own, and lastly where the true color was seen. It may sometimes appear as if no points beyond the limits for the color had been determined when it will be found that there is a wide zone, beyond the real limits for the color where it is seen as an entirely different color. For example, orange with the dark backgrounds would have an outer zone where it would not be seen as a color, a second zone where it would be seen as yellow, a third where it would appear yellowish orange and lastly one where its true color tone would be distinguished.

TABLE III D. Lower Meridian.

Background.	Color.	Color Seen.	Degrees on the Retina.											
			13-22	25	27.5	30	33	35	37	39	41.5	43	45	47
For blue.	Red.	Red.						I			I	I		**1**
" green.	"	"									I	2	**1** 3	**1**
" yellow.	"	"								I			**1**	
For blue.	Red.	Orange.			I		I		I		I	I?	I	2
" green.	"	"												
" yellow.	"	"										I?		
For blue.	Orange.	Orange.			I									**2**
" green.	"	"			I					I	I	2	**1**	**2**
" yellow.	"	"	3			I	I			1				**1**
For blue.	Orange.	Yellowish-orange.								I	I.	I	I I.	
" green.	"	"												
" yellow.	"	"												
For blue.	Orange.	Yellow.											I	
" green.	"	"												
" yellow.	"	"					I	I	I					
For yellow.	Orange.	Red.	2	I									I	
For blue.	Green.	Green.						**1**	**1**			**1**		
" green.	"	"									**2**			
" yellow.	"	"	I	I		I		I	**1**	**1**				
For blue.	Green.	Greenish-yellow.								I				
" green.	"	"						I						
" yellow.	"	"												
For blue.	Green.	Yellow.			2						I			
" green.	"	"									I			
" yellow.	"	"					I							

TABLE I A. NASAL MERIDIAN.

Background.	Color.	Color Seen.	Degrees on the Retina.															
			10-39	41.5	43	47	50	55	55.5	57	60.5	62	62.5	63.5	64.5	67	68	69.5
For blue.	Red.	Red.	3	II.			2	2	1 I.		1 I.				I.	1		1
" red.	"	"														I.		
" green.	"	"													2	2		
" yellow.	"	"	1	1		1	1				1				2	4		3
For blue.	Red.	Orange.					1				1 I.					1		1
" red.	"	"																
" green.	"	"																
" yellow.	"	"														1		1
For blue.	Red.	Yellow.								1								
" red.	"	"																
" green.	"	"																
" yellow.	"	"																
For blue.	Orange.	Orange.	II.	III.			V.		II.	V.					I.	II.		
" red.	"	"														I.		2
" green.	"	"											1	I.	3	2		I.
" yellow.	"	"		1			2				2				2	1		1
For blue.	Orange.	Yellowish-orange.				II.	1								2	1		
" red.	"	"														I.	I.	
" green.	"	"											1	I.				
" yellow.	"	"														2		
For blue.	Orange.	Yellow.																2
" red.	"	"																
" green.	"	"																
" yellow.	"	"																
For green.	Orange.	Red.																
" yellow.	"	"	3	2	1				2						2	1		3
For blue.	Green.	Green.							1		1							1
" red.	"	"														3		1
" green.	"	"									1	1				I.		I.
" yellow.	"	"									2				3 2	1 2		1
For blue.	Green.	Greenish-yellow.									1				1			
" red.	"	"											1		1			1
" green.	"	"											1		I.	II.		I.
" yellow.	"	"																
For blue.	Green.	Yellow.													2		2	
" red.	"	"																
" green.	"	"																
" yellow.	"	"																

TABLE I A. NASAL MERIDIAN.—*Continued.*

Background.	Color.	Color Seen.	Degrees on the Retina.																
			70.5	72	73	74.5	76	77	78.5	80	81	82.5	84	85.5	87	88.5	90	91.5	92.5
For blue.	Red.	Red.			1	1													
" red.	"	"			1			I.		2					1 **1**				1 **1**
" green.	"	"			1	2	3			2	2	1 **1**	**1**		**1**	**1**		**1**	
" yellow.	"	"			1	**1**	2			4 **2**		**1**	**1**	1 **1**	2 **2**				**1**
For blue.	Red.	Orange.			1					2			1						
" red.	"	"					1						1		1				
" green.	"	"					1												
" yellow.	"	"																	
For blue.	Red.	Yellow.				1						1		1					
" red.	"	"											1		1	1			
" green.	"	"																	
" yellow.	"	"																	
For blue.	Orange.	Orange.			1								**1**						**1**
" red.	"	"																	
" green.	"	"		1	1													**1**	**1**
" yellow.	"	"				1	1					1	1 **1**	**1**	**1**		**1**		
For blue.	Orange.	Yellowish-orange.																	
" red.	"	"										I.							
" green.	"	"			1					1	1								
" yellow.	"	"					1			1									
For blue.	Orange.	Yellow.			1					2		3		1	1				
" red.	"	"	1	1		1				1			1	2	2		2	1	1
" green.	"	"								1	1	1		2				1	3
" yellow.	"	"													1				
For green.	Orange.	Red.			1														
" yellow.	"	"		1	3					3		1	1		3				
For blue.	Green.	Green.																	
" red.	"	"			1		**1**			2		2				**2**	**2**		**2**
" green.	"	"											**1**	**1**	**1**			**1**	**1**
" yellow.	"	"			**1**		**2**			**3**					**1**	**1**		**1**	
For blue.	Green.	Greenish-yellow.																	
" red.	"	"		1		2				1									
" green.	"	"		I.	I.														
" yellow.	"	"																	
For blue.	Green.	Yellow.			2					1		1							
" red.	"	"			1	1		1		1		1	1		2		1		1
" green.	"	"			1		2	2			1		1	1	1		2		1
" yellow.	"	"																	

TABLE II A. NASAL MERIDIAN.

Background.	Color.	Color Seen.	Degrees on the Retina.											
			10–39	41.5	43	47	50	51	55.5	57	60.5	62	62.5	63.5
For blue.	Red.	Red.		I.			I.		II.					
" red.	"	"												
" green.	"	"		3			1		1		1			
" yellow.	"	"							1					
For blue.	Red.	Orange.									II.			
" red.	"	"												
" green.	"	"												
" yellow.	"	"												
For blue.	Red.	Yellow.												
" red.	"	"												
" green.	"	"												
" yellow.	"	"												
For blue.	Orange.	Orange.	I.	I.			I.							
" red.	"	"	2								I.			
" green.	"	"		2					2	2	I. 2			
" yellow.	"	"	2											
For blue.	Orange.	Yellowish-orange.							I.		II.			
" red.	"	"												
" green.	"	"		2										
" yellow.	"	"												
For blue.	Orange.	Yellow.												
" red.	"	"												
" green.	"	"												
" yellow.	"	"												
For green.	Orange.	Red.	1	1					I.					
" yellow.	"	"	2	2			I. 1		2		1	1		1
For blue.	Green.	Green.												
" red.	"	"												
" green.	"	"		1			1		2		2 I.			
" yellow.	"	"												
For blue.	Green.	Yellowish-green.												
" red.	"	"									1			
" green.	"	"												
" yellow.	"	"												
For blue.	Green.	Yellow.												
" red.	"	"												1
" green.	"	"												
" yellow.	"	"												

Table II A. Nasal Meridian.—*Continued.*

Background.	Color.	Color Seen.	Degrees on the Retina.											
			64.5	67	68	69	70.5	72	73	74.5	76	77	78.5	80
For blue.	Red.	Red.	1.											
" red.	"	"		1				1	1					2
" green.	"	"	1	1				1				1		1
" yellow.	"	"												
For blue.	Red.	Orange.		2										1.
" red.	"	"												
" green.	"	"												
" yellow.	"	"												
For blue.	Red.	Yellow.	1											
" red.	"	"									1			
" green.	"	"												
" yellow.	"	"												
For blue.	Orange.	Orange.	1.											
" red.	"	"												
" green.	"	"	1	2					1					1.
" yellow.	"	"												
For blue.	Orange.	Yellowish-orange.	1.	1					1					1
" red.	"	"	1					1	1					
" green.	"	"					1			3				1.
" yellow.	"	"												
For blue.	Orange.	Yellow.		1										
" red.	"	"								1		1		1
" green.	"	"										1		
" yellow.	"	"												
For green.	Orange.	Red.	2					1						
" yellow.	"	"				1						1		
For blue.	Green.	Green.												
" red.	"	"												
" green.	"	"	1			2								
" yellow.	"	"	1.			1				1				1
For blue.	Green.	Yellowish-green.												
" red.	"	"		1		1			1					
" green.	"	"		2					1	2		1. 1	1. 1	
" yellow.	"	"												
For blue.	Green.	Yellow.												1
" red.	"	"								1		1		1
" green.	"	"	3	1						1		1		1
" yellow.	"	"												

TABLE II A. NASAL MERIDIAN.—*Continued.*

Background.	Color.	Color Seen.	Degrees on the Retina.											
			81	82.5	84	85.5	87	88.5	90	91.5	92.5	94	95.5	97
For blue.	Red.	Red.			I									
" red.	"	"			2		1			1		1	1	I
" green.	"	"	I	I 1	I 1	1	1	1						
" yellow.	"	"		I		1	I							
For blue.	Red.	Orange.												
" red.	"	"	I	I										
" green.	"	"												
" yellow.	"	"												
For blue.	Red.	Yellow.			I							I		
" red.	"	"												
" green.	"	"	2											
" yellow.	"	"												
For blue.	Orange.	Orange.												
" red.	"	"											1	
" green.	"	"	I.	I.									1	
" yellow.	"	"				I		1				2		
For blue.	Orange.	Yellowish-orange.												
" red.	"	"					I							
" green.	"	"		I										
" yellow.	"	"												
For blue.	Orange.	Yellow.			I	I						I		
" red.	"	"		I	I					I	I	I		
" green.	"	"	2	I	I			I		I				
" yellow.	"	"												
For green.	Orange.	Red.												
" yellow.	"	"		2		I				I				
For blue.	Green.	Green.											1	
" red.	"	"											1	
" green.	"	"								1	1			
" yellow.	"	"		1		1		1		1				
For blue.	Green.	Yellowish-green.												
" red.	"	"				I								
" green.	"	"			I.			I						
" yellow.	"	"												
For blue.	Green.	Yellow.			I		I					I		
" red.	"	"			I				I	I		I		
" green.	"	"		2					I			I		
" yellow.	"	"												

TABLE III A. NASAL MERIDIAN.

Background.	Color.	Color Seen	Degrees on the Retina.											
			10–39	41.5	43	47	50	55	55.5	57	60.5	62	62.5	63.5
For blue.	Red.	Red.							I.		I.			
" red.	"	"							I.		I. 1			
" green.	"	"									1			
" yellow.	"	"	1	2			1		1					
For blue.	Red.	Orange.												
" red.	"	"									I.			
" green.	"	"												
" yellow.	"	"												
For blue.	Red.	Yellow.												
" red.	"	"												
" green.	"	"												
" yellow.	"	"												
For blue.	Orange.	Orange.		I.			I.		II.					
" red.	"	"	2	3			1				II.			
" green.	"	"									I.			
" yellow.	"	"	1											
For blue.	Orange.	Orange-yellow.												
" red.	"	"												
" green.	"	"												
" yellow.	"	"												
For blue.	Orange.	Yellow.												
" red.	"	"												
" green.	"	"												
" yellow.	"	"												
For green.	Orange.	Red.	1	1					1		2			1
" yellow.	"	"	5		1	2			3		1			
For blue.	Green.	Green.												
" red.	"	"												
" green.	"	"										1		
" yellow.	"	"										1		
For blue.	Green.	Greenish-yellow.												
" red.	"	"												
" green.	"	"												
" yellow.	"	"												
For blue.	Green.	Yellow.												
" red.	"	"												
" green.	"	"												
" yellow.	"	"												

TABLE III A. NASAL MERIDIAN.—*Continued.*

Background.	Color.	Color Seen.	Degrees on the Retina.											
			64.5	67	68	69	70.5	72	73	74.5	76	77	78.5	80
For blue.	Red.	Red.		I.						I.				
" red.	"	"	2	1		II.	II. 1	2	2	2	1	3 III.		1
" green.	"	"			1									
" yellow.	"	"				1		2		1		2		1
For blue.	Red.	Orange.								I.		I.		I. 1
" red.	"	"												II. 1
" green.	"	"												I.
" yellow.	"	"												
For blue.	Red.	Yellow.												
" red.	"	"												1
" green.	"	"												
" yellow.	"	"												
For blue.	Orange.	Orange.		I.				I.						
" red.	"	"	1	1									II.	
" green.	"	"		I.								I.		II.
" yellow.	"	"												2
For blue.	Orange.	Orange-yellow.												
" red.	"	"							I.			II.		1
" green.	"	"												
" yellow.	"	"					1							
For blue.	Orange.	Yellow.								1		2		1
" red.	"	"												
" green.	"	"												
" yellow.	"	"												
For green.	Orange.	Red.	I.											
" yellow.	"	"	5	1		2		2		1		3	1	1
For blue.	Green.	Green.												1
" red.	"	"												
" green.	"	"	1	1				1						1
" yellow.	"	"	1	1		1							1	
For blue.	Green.	Greenish-yellow.												
" red.	"	"								2				
" green.	"	"										1		
" yellow.	"	"												
For blue.	Green.	Yellow.												
" red.	"	"												
" green.	"	"												
" yellow.	"	"							1					

TABLE III A. NASAL MERIDIAN.—*Continued.*

Background.	Color.	Color Seen.	Degrees on the Retina.											
			81	82.5	84	85.5	87	88.5	90	91.5	92.5	94	95.5	97
For blue.	Red.	Red.		I								2		
" red.	"	"	III.							I		2		
" green.	"	"				I		2		1	1			
" yellow.	"	"		I			1		1		1			
For blue.	Red.	Orange.		I. I										
" red.	"	"		II.			I. I	I.						
" green.	"	"		I.										
" yellow.	"	"												
For blue.	Red.	Yellow.					I							
" red.	"	"			3	I	2	2						
" green.	"	"				I		I				2		
" yellow.	"	"												
For blue.	Orange.	Orange.												
" red.	"	"			1						1			
" green.	"	"				1						1		1
" yellow.	"	"		I	1	1	1		1					
For blue.	Orange.	Orange-yellow.							I.					
" red.	"	"					I							
" green.	"	"							I					
" yellow.	"	"												
For blue.	Orange.	Yellow.		I			I		I	I				
" red.	"	"				I				I				
" green.	"	"		I		I		I		3				
" yellow.	"	"								I				
For green.	Orange.	Red.												
" yellow.	"	"				2		I						
For blue.	Green.	Green.					I	I 1						
" red.	"	"		I						1				
" green.	"	"	I				2			1	1			
" yellow.	"	"												
For blue.	Green.	Greenish-yellow.												
" red.	"	"				I	I							
" green.	"	"		I		I			I					
" yellow.	"	"												
For blue.	Green.	Yellow.												
" red.	"	"					I	I						
" green.	"	"						I						
" yellow.	"	"				I								

TABLE IV A. NASAL MERIDIAN.

Background.	Color.	Color Seen.	Degrees on the Retina.																	
			10-39	41.5	43	47	50	55	55.5	57	60.5	62	62.5	63.5	64.5	67	68	69.5	70.5	72
For blue.	Red.	Red.													II.	I.		1		
" red.	"	"														1		1		1
" green.	"	"							1		I.					1		1		
" yellow.	"	"							1						4	2		3		
For blue.	Red.	Orange.									1					1 I.				
" red.	"	"																	1	
" green.	"	"																		
" yellow.	"	"																1		
For blue.	Red.	Yellow.																		
" red.	"	"																		
" green.	"	"																		
" yellow.	"	"																		
For blue.	Orange.	Orange.								I.					I.	I.				
" red.	"	"													1					
" green.	"	"													1					
" yellow.	"	"													2					
For blue.	Orange.	Orange-yellow.									I. 1				II.			1		
" red.	"	"														I.		I.		1
" green.	"	"																1		
" yellow.	"	"													1	2				
For blue.	Orange.	Yellow.														1				1
" red.	"	"																		
" green.	"	"																		
" yellow.	"	"																		
For green.	Orange.	Red.														1				
" yellow.	"	"		1			1		2		I. 1				2	2		2		
For blue.	Green.	Green.														2				
" red.	"	"														1		1	1	
" green.	"	"													1	2	1			2
" yellow.	"	"														1 2		1		
For blue.	Green.	Greenish-yellow.																1		
" red.	"	"																	1	
" green.	"	"																		
" yellow.	"	"																		
For blue.	Green.	Yellow.									1									
" red.	"	"																		
" green.	"	"																		
" yellow.	"	"																		

TABLE IV A. NASAL MERIDIAN.—*Continued.*

Background.	Color.	Color Seen.	Degrees on the Retina.																	
			73	74.5	76	77	78.5	80	81	82.5	84	85.5	87	88.5	90	91.5	92.5	94	95.5	97
For blue.	Red.	Red.			1			2		1								1		
" red.	"	"	2					3					1	1		2	1			
" green.	"	"			1		1				2		2	2	1					
" yellow.	"	"	2	1	1	1		7		2	1	2		1						
For blue.	Red.	Orange.						1			1									
" red.	"	"									2			1	1	1				
" green.	"	"											2							
" yellow.	"	"										1								
For blue.	Red.	Yellow.									1									
" red.	"	"																		
" green.	"	"																		
" yellow.	"	"																		
For blue.	Orange.	Orange.											1					1		
" red.	"	"												2					3	
" green.	"	"											1.		1		1			
" yellow.	"	"		2								1		2			1	1		
For blue.	Orange.	Orange-yellow.			1			1. 2												
" red.	"	"	1					2		1	1									
" green.	"	"			1			1			1	1	4	1						
" yellow.	"	"	1					1		1										
For blue.	Orange.	Yellow.						1		1	1		2		1					
" red.	"	"									1		1	1				2		
" green.	"	"																1		
" yellow.	"	"												1						
For green.	Orange.	Red.	1			1														
" yellow.	"	"	3		1	2		5		2	4									
For blue.	Green.	Green.																		
" red.	"	"														1	3	1		
" green.	"	"	1		1			3	1	1	1		1 1	1		1		2		
" yellow.	"	"	1 1	1	1											1				
For blue.	Green.	Greenish-yellow.	1					2			1									
" red.	"	"	2					2		1	2		1							
" green.	"	"					2					1	3	1						
" yellow.	"	"																		
For blue.	Green.	Yellow.										2								
" red.	"	"											1			1				
" green.	"	"						1					1	1	1		1			
" yellow.	"	"																		

TABLE I B. TEMPORAL MERIDIAN.

Background.	Color.	Color Seen.	Degrees on the Retina.											
			13–25	27.5	30	33	35	37	39	41.5	43	45	47	48
For blue.	Red.	Red.	6	4		2			1				**1**	
" green.	"	"	1				1	1	1	1 **1**	**1**			
" yellow.	"	"	7	1	3	1	1	2		**2**				
For blue.	Red.	Orange.				1			2 I.					
" green.	"	"				1			1					
" yellow.	"	"												
For blue.	Orange.	Orange.	3 II.	1 I.			**1**			**2**				
" green.	"	"	1	1			1		3		1 **2**			
" yellow.	"	"	5 R[1]		2 R	1	1 ?	1 ? R	1	1	**1**	**2**		
For blue.	Orange.	Yellowish-orange.		1		1								
" green.	"	"				1 I.	1	1	1	1				
" yellow.	"	"							1 ?					
For blue.	Orange.	Yellow.					1		3	1	1			
" green.	"	"							1	1	2			
" yellow.	"	"			1									
For green.	Orange.	Red.			1					1			1 ?	
" yellow.	"	"	1	1				1						
For blue.	Green.	Green.	5	2	1				**1**				**1**	
" green.	"	"	2					**1**	1 ?		**1**			
" yellow.	"	"	6		2	1		3	1 ?	**1**				
For blue.	Green.	Greenish-yellow.	1	1										
" green.	"	"	1	1		**2**	1	2	3		1			
" yellow.	"	"			1			1		1				
For blue.	Green.	Yellow.		2				2						
" green.	"	"												
" yellow.	"	"												

[1] R = Reddish orange.

TABLE II B. TEMPORAL MERIDIAN.

Background.	Color.	Color Seen.	Degrees on the Retina.												
			13–25	27.5	30	33	35	37	39	41.5	43	45	47	48	50
For blue.	Red.[1]	Red.	II.					2		1	1 2				
" green.	"	"							2						
" yellow.	"	"	1				1								
For blue.	Orange[1]	Orange.		2		2	1			1					
" green.	"	"													
" yellow.	"	"													
For blue.	Orange.	Orange.	I.	I.				1	1	1	1				
" green.	"	"		I.			1	1	1	1	1	1			
" yellow.	"	"		1			1		1	1					
For blue.	Orange.	Yellowish-orange.	III.		1										
" green.	"	"													
" yellow.	"	"													
For blue.	Orange.	Yellow.				1	1	2		1	1				
" green.	"	"							1		1				
" yellow.	"	"		1		1									
For green.	Orange.	Red.													
" yellow.	"	"	4		1		1 ?								
For blue.	Green.	Green.	1 V.												
" green.	"	"						2	1	1					
" yellow.	"	"	2 1 ?	1		2	1								
For blue.	Green.	Greenish-yellow.	I.												
" green.	"	"				1	1	1							
" yellow.	"	"													
For blue.	Green.	Yellow.		2		2		3		1	1				
" green.	"	"									1				
" yellow.	"	"			1										

[1] Omitted in averages because incomplete.

TABLE III B. TEMPORAL MERIDIAN.

Background.	Color.	Color Seen.	Degrees on the Retina.													
			13–27.5	30	33	35	37	39	41.5	43	45	47		50	51	52.5
For blue.	Red.	Red.	2	2 I.			1		2		I.					2
" green.	"	"	1	1			1		2 I.		1	1	1			
" yellow.	"	"	3				2		1							
For blue.	Red.	Orange.		1							1		2			
" green.	"	"											1			
" yellow.	"	"														
For blue.	Orange.	Orange.	IV.	II.					1		1	1		1	1	1
" green.	"	"	1	1					3		3	1				
" yellow.	"	"							1			2				
For blue.	Orange.	Yellowish-orange.	1	1 I.			1		1 II.		1	II.				
" green.	"	"									1	1				
" yellow.	"	"							1				11?			
For blue.	Orange.	Yellow.								1	1	1				
" green.	"	"										2				
" yellow.	"	"							1							
For green.	Orange.	Red.														
" yellow.	"	"	2	2			1 I.		1 I.							
For blue.	Green.	Green.	2	2			1		1	1	2	1				
" green.	"	"	1				1		3		1	1	2	1		
" yellow.	"	"	2	2			1		1	2	1	1				
For blue.	Green.	Greenish-yellow.	1?	2	1 I.											
" green.	"	"		1							2					
" yellow.	"	"														
For blue.	Green.	Yellow.							1							
" green.	"	"														
" yellow.	"	"														

TABLE I C. UPPER MERIDIAN.

Background.	Color.	Color Seen.	Degrees on the Retina.									
			10–33	35	37	39	41.5	43	45	47	48	50
For blue.	Red.	Red.	3	1			1		2			
" green.	"	"	2				3	1	1	3	1 1	2 3
" yellow.	"	"	2				1			2		3
For blue.	Red.	Orange.			1	2	1		1	2	3	3
" green.	"	"			1		1		2	3	1	1
" yellow.	"	"										
For blue.	Red.	Yellow.										
For blue.	Orange.	Orange.	2 I.		1	1	1					
" green.	"	"	2	1			3	2		2	3	2 3
" yellow.	"	"	2				1					1
For blue.	Orange.	Yellowish-orange.					1					
" green.	"	"	I.				2			1		
" yellow.	"	"										
For blue.	Orange.	Yellow.					2		1			3
" green.	"	"					1	2			1	2
" yellow.	"	"										
For green.	Orange.	Red.	3									1
" yellow.	"	"	5									
For blue.	Green.	Green.	3	1	1		1 ?					1
" green.	"	"	2 I.								1 ?	2
" yellow.	"	"	3				1					
For blue.	Green.	Greenish-yellow.			1		1					
" green.	"	"	3				2			1		
" yellow.	"	"	1									
For blue.	Green.	Yellow.	2				2	1	1	1		2
" green.	"	"					1		1	1	1	1
" yellow.	"	"										

TABLE I C. UPPER MERIDIAN.—*Continued.*

Background.	Color.	Color Seen.	Degrees on the Retina								
			51	52.5	54	55	56	57	58	59	60
For blue.	Red.	Red.						1			
" green.	"	"	1?	2	1	1	3	1	1	1	
" yellow.	"	"	4	4 2	1 1?	2 2	2				
For blue.	Red.	Orange.		2		1	1				
" green.	"	"									
" yellow.	"	"									
For blue.	Red.	Yellow.			1	1					
For blue.	Orange.	Orange.		1			1		1	1	
" green.	"	"	1		1		2	2		1	1
" yellow.	"	"	1	1	1	1					
For blue.	Orange.	Yellowish-orange.									
" green.	"	"			1						
" yellow.	"	"									
For blue.	Orange.	Yellow.		1	1	1	1	1			
" green.	"	"					2	1			
" yellow.	"	"									
For green.	Orange.	Red.									
" yellow.	"	"									
For blue.	Green.	Green.			1		1	1			
" green.	"	"		1	2		1				
" yellow.	"	"									
For blue.	Green.	Greenish-yellow.									
" green.	"	"	1	1							
" yellow.	"	"									
For blue.	Green.	Yellow.		1		1		1			
" green.	"	"									
" yellow.	"	"									

TABLE II C. UPPER MERIDIAN.

Background	Color.	Color Seen.	Degrees on the Retina.							
			10–33	35	37	39	41.5	43	45	47
For blue.	Red.	Red.	2	1		1		1		
" green.	"	"			1	1	2			2
" yellow.	"	"	4					1		1
For blue.	Red.	Orange.	2	1		1	2	1		2
" green.	"	"								
" yellow.	"	"								
For blue.	Red.	Yellow.								
For blue.	Orange.	Orange.	3				1			
" green.	"	"	4		2	1	1	2 1		2
" yellow.	"	"	1							
For blue.	Orange.	Yellowish-orange.	I. 2	II.			1			
" green.	"	"			1					
" yellow.	"	"								
For blue.	Orange.	Yellow.					1	1		3
" green.	"	"								
" yellow.	"	"								
For green.	Orange.	Red.	7			1				
" yellow.	"	"	6	2		1				
For blue.	Green.	Green.	2 I.		1	1	1	1 1		
" green.	"	"	3	1			1	1		
" yellow.	"	"	2				1	1		
For blue.	Green.	Greenish-yellow.	1	2					1 I.	
" green.	"	"	3		1 ?				1	
" yellow.	"	"	1	2						
For blue.	Green.	Yellow.							1	
" green.	"	"	1			1			1	1
" yellow.	"	"								

TABLE II C. UPPER MERIDIAN.—*Continued.*

Background.	Color.	Color Seen.	Degrees on the Retina.						
			48	50	51	52.5	54	55	56
For blue.	Red.	Red.						1 1	1
" green.	"	"					1	1	1
" yellow.	"	"			1				
For blue.	Red.	Orange.				1			
" green.	"	"		2					
" yellow.	"	"							
For blue.	Red.	Yellow.				1			
For blue.	Orange.	Orange.			1	1			
" green.	"	"		1	2		1	2	
" yellow.	"	"							
For blue.	Orange.	Yellowish-orange.							
" green.	"	"							
" yellow.	"	"							
For blue.	Orange.	Yellow.							
" green.	"	"		1					
" yellow.	"	"							
For green.	Orange.	Red.							
" yellow.	"	"							
For blue.	Green.	Green.		1					
" green.	"	"			1	1		2	1
" yellow.	"	"							
For blue.	Green.	Greenish-yellow.							
" green.	"	"					1		
" yellow.	"	"							
For blue.	Green.	Yellow.							
" green.	"	"							
" yellow.	"	"							

TABLE III C. UPPER MERIDIAN.

Background.	Color.	Color Seen.	Degrees on the Retina.																		
			3–33	35	37	39	41.5	43	45	47	48	50	51	52½	54	55	56	57	58	59	60
For blue.	Red.	Red.	3 I.			1	1	1			1										
" green.	"	"	1		1		2	1				2		1	2	2 **1**	**2** 1				
" yellow.	"	"	1	1	2	2	3 **1**	2	1 **1**	1 **2**	1	1	**1**		1	1 1	1 **2**				
For blue.	Red.	Orange.			1	1															
For blue.	Orange.	Orange.	III. 1	I.	1?																
" green.	"	"	4		2						1										**2** 1
" yellow.	"	"	1		1	2				**1**			**1**				**1**				
For blue.	Orange.	Yellowish-orange.				II.	1 I.	1				I.									
" green.	"	"										1			1		1			1	2
" yellow.	"	"																			
For green.	Orange.	Red.	2	1			1					1		1			1				
" yellow.	"	"	2		2	2	2		1	1			2	1		1					
For blue.	Green.	Green.	2 I.		1**1**	1	**1**	1 **1**				**1**									
" green.	"	"	4	**1**		**1**	**1**						**1**	**1**	**2**						
" yellow.	"	"	2					**1**													
For blue.	Green.	Greenish-yellow.	2	2						1 I.											
" green.	"	"	4		1?					1					1						
" yellow.	"	"	1	2																	
For blue.	Green.	Yellow.								1											
" green.	"	"	1			1				1	1										
" yellow.	"	"	2																		

TABLE I D. LOWER MERIDIAN.

Background.	Color.	Color Seen.	Degrees on the Retina.											
			13-22	25	27.5	30	33	35	37	39	41.5	43	45	47
For blue.	Red.	Red.			1	1								
" green.	"	"	3	2		1	3	2 **3**	**1**	**2**				
" yellow.	"	"					1	1	1	**1**				
For blue.	Red.	Orange.			1		1	2						
" green.	"	"												
" yellow.	"	"					1							
For blue.	Orange.	Orange.			1	I.			1			**1**	**1**	
" green.	"	"	3	2				1	2	**2**	**2**			
" yellow.	"	"						1			1	**1**	**1**	
For blue.	Orange.	Yellowish-orange.					1	1 I.		1	1			
" green.	"	"												
" yellow.	"	"												
For green.	Orange.	Red.	1		1			1		1				
" yellow.	"	"	2 I.	I.	1		1							
For blue.	Green.	Green.	1					**1**						
" green.	"	"	1				**1**		**1**		**1**			
" yellow.	"	"	2	1	1?		**2**							
For blue.	Green.	Greenish-yellow.	1				1	1						
" green.	"	"	2		1	1	1	1						
" yellow.	"	"												
For blue.	Green.	Yellow.						1	1					
" green.	"	"							1	1				
" yellow.	"	"												

TABLE II D. Lower Meridian.[1]

Background.	Color.	Color Seen.	Degrees on the Retina.											
			13-22	25	27·5	30	33	35	37	39	41·5	43	45	47
For blue.	Red.	Red.	2 1.	1								1		
" green.	"	"			1		1		2		1	1		
" yellow.	"	"		1	1				1		1			
For blue.	Red.	Orange.					1		1	1	1			
" green.	"	"												
" yellow.	"	"												
For blue.	Red.	Yellow.									2	1?		
For blue.	Orange.	Orange.	2 1							1		1	1	
" green.	"	"	2	1		1			1		1		1	
" yellow.	"	"				1								
For blue.	Orange.	Yellowish-orange.					1		1					
" green.	"	"							1					
" yellow.	"	"	1											
For blue.	Orange.	Yellow.										1		
" green.	"	"							1	1				
" yellow.	"	"					1							
For green.	Orange.	Red.												
" yellow.	"	"		1	1		1							
For blue.	Green.	Green.	1					1		1				
" green.	"	"	1											
" yellow.	"	"												
For blue.	Green.	Greenish-yellow.	1.											
" green.	"	"												
" yellow.	"	"												
For blue.	Green.	Yellow.	1		1		1		1					
" green.	"	"			1		1		2					
" yellow.	"	"												

[1] For Table III D, see p. 406.

EDITORS' ANNOUNCEMNT.

His colleagues regret that stress of other duties compels Professor Warren to relinquish the duties of the position of Business Manager of the REVIEW publications. In his place Dr. J. W. Baird, of the Johns Hopkins University, will assume the Business Management. We append a statement of the present location of the responsible bureaus of the REVIEW, with the appropriate addresses for the various sorts of communication.

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